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**GEORGE C. MARSHALL**

**SPACE  
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**HUNTSVILLE, ALABAMA**

**ORBITAL PARAMETERS FOR ARTIFICIAL EARTH  
SATELLITES UP TO 40,000 KM ALTITUDE**

By

Walter H. Stafford ,  
Sam H. Harlin, *sd*  
Carmen R. Catalfamo *29 aug. 1963 regis*

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ABSTRACT

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*Author*

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FLIGHT OPERATIONS SECTION  
ADVANCED FLIGHT SYSTEMS BRANCH  
PROPULSION AND VEHICLE ENGINEERING DIVISION

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## DEFINITION OF SYMBOLS

Symbol	Definition
$a$	Semi-major axis, km
$b$	Semi-minor axis, km
$e$	Eccentricity
$h_a$	Apocenter altitude, km
$h_k$	Circular orbital altitude, km
$h_p$	Pericenter altitude, km
$p$	Parameter
$r_a$	Apocenter radius, km
$r_e$	Equatorial radius, 6378.27 km
$r_k$	Circular orbital radius, km
$r_p$	Pericenter radius, km
$P$	Orbital period, min
$V_a$	Apocenter velocity, km/sec
$V_k$	Circular orbital velocity, km/sec
$V_p$	Pericenter velocity, km/sec
$\Delta V$	Characteristic velocity, km/sec
$\mu$	Earth gravitational constant, $398,606.6 \text{ km}^3/\text{sec}^2$

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SUMMARY

Data were generated to assist in the initial sizing of vehicles for lunar and interplanetary missions. Section A is a series of graphs concerning circular orbits from 0 to 40,000 km altitude. Section B is a series of graphs for transfer from circular orbits of 0 to 400 km altitude to other circular orbits of altitudes up to 40,000 km altitude. The velocity required to enter a given transfer ellipse and also the velocity required to circularize at apogee of the transfer ellipse are given.

INTRODUCTION

A series of graphs of various orbital elements about the earth for orbits of 0 to 40,000 km altitude is presented in this report. The velocity required to enter a transfer ellipse can be readily determined, also, the velocity required to circularize at apocenter of the transfer ellipse. These data will assist in determining the capability required for a vehicle to accomplish an earth mission, and a lunar or interplanetary mission via Earth Orbit Rendezvous Mode.

DISCUSSION

A series of graphs of various orbital elements about the earth for orbits from 0 to 40,000 km altitude is presented in this report. The data is divided into two distinct categories: Section A is a series of



graphs for circular orbits from 0 to 40,000 km altitude; Section B is a series of graphs for eccentric orbits with pericenter altitude lying in the 0 to 400 km altitude range and whose apocenter altitude lies in the 1,000 to 40,000 km altitude range.

The total velocity required to transfer from one circular orbit to another circular orbit (Figure 1) is given in two parts: part one is the transfer velocity, i. e., the difference between the initial circular orbit velocity and the pericenter velocity of the transfer ellipse; part two is the circularization velocity, i. e., the difference between the apocenter velocity of the transfer ellipse and the velocity of the final circular orbit. The addition of parts one and two then will give the total velocity increment needed for the maneuver.

The data were computed using the following equations:

Semi-major axis

$$a = \frac{r_p}{1 - e} = \frac{r_a}{1 + e} \quad (1)$$

Eccentricity

$$e = \frac{\frac{r_a}{a} - \frac{r_p}{a}}{\frac{r_a}{a} + \frac{r_p}{a}} = \frac{V_p - V_a}{V_p + V_a} \quad (2)$$

For evaluation of the parameter

$$p = a(1 - e^2) = r_p(1 + e) \quad (3)$$

Apocenter radius (distance from focus to apocenter)

$$r_a = a(1 + e) = \frac{p}{1 - e} \quad (4)$$

Pericenter radius (distance from focus to pericenter)

$$r_p = a(1 - e) = \frac{p}{1 + e} \quad (5)$$

Orbital period

$$P = 2\pi \sqrt{\frac{a^3}{\mu}} = 2\pi \sqrt{\frac{r_a^3}{\mu(1+e)^3}} \quad (6)$$

For evaluation of speed at apocenter

$$V_a = \sqrt{\left(\frac{\mu}{a}\right) \left(\frac{1-e}{1+e}\right)} = \sqrt{\left(\frac{\mu}{r_a}\right) (1-e)} \quad (7)$$

For evaluation of speed at pericenter

$$V_p = \sqrt{\left(\frac{\mu}{a}\right) \left(\frac{1+e}{1-e}\right)} = \sqrt{\left(\frac{\mu}{r_p}\right) (1+e)} \quad (8)$$

## ILLUSTRATIONS

### SECTION A

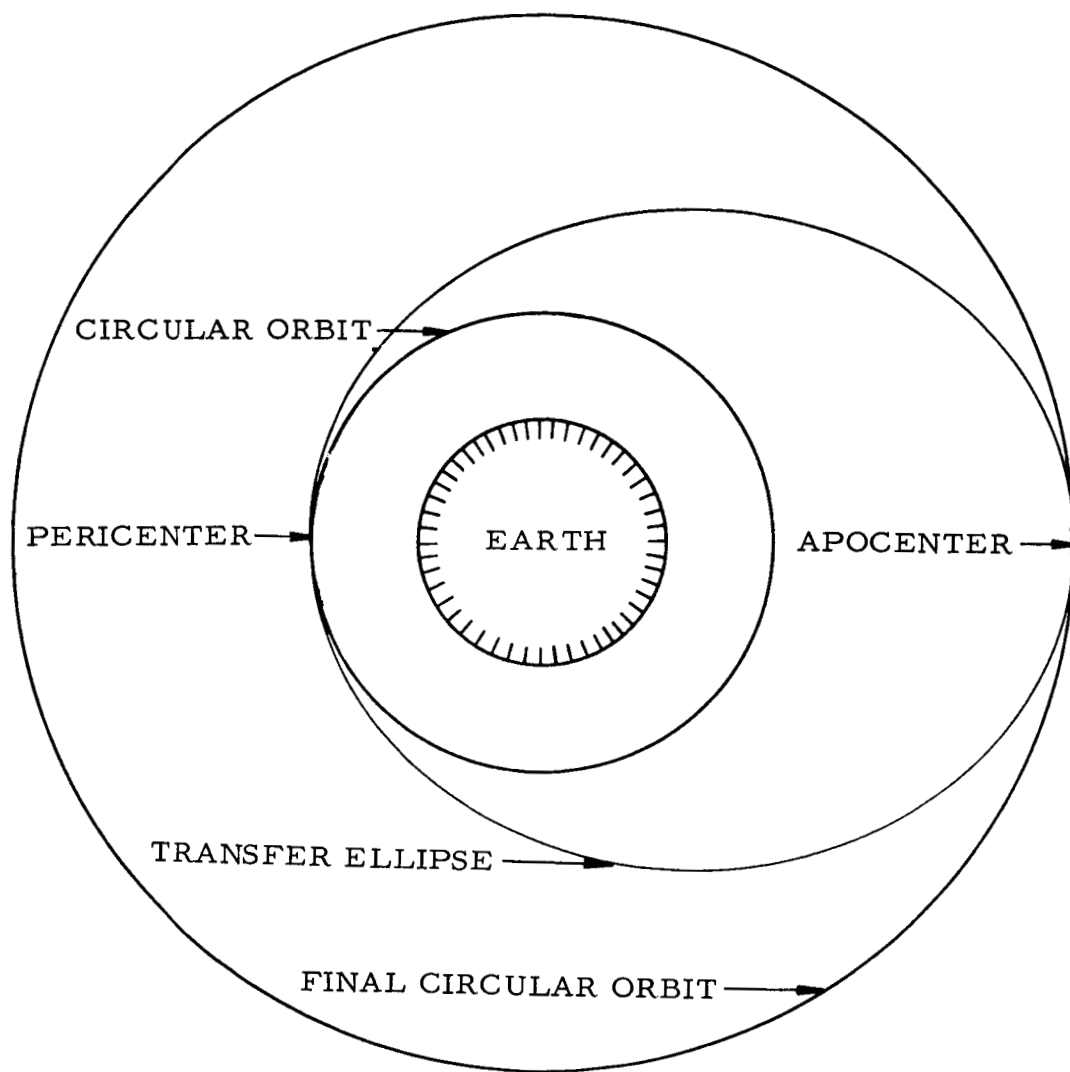


FIGURE 1. GEOMETRY OF THE ORBITAL PARAMETERS

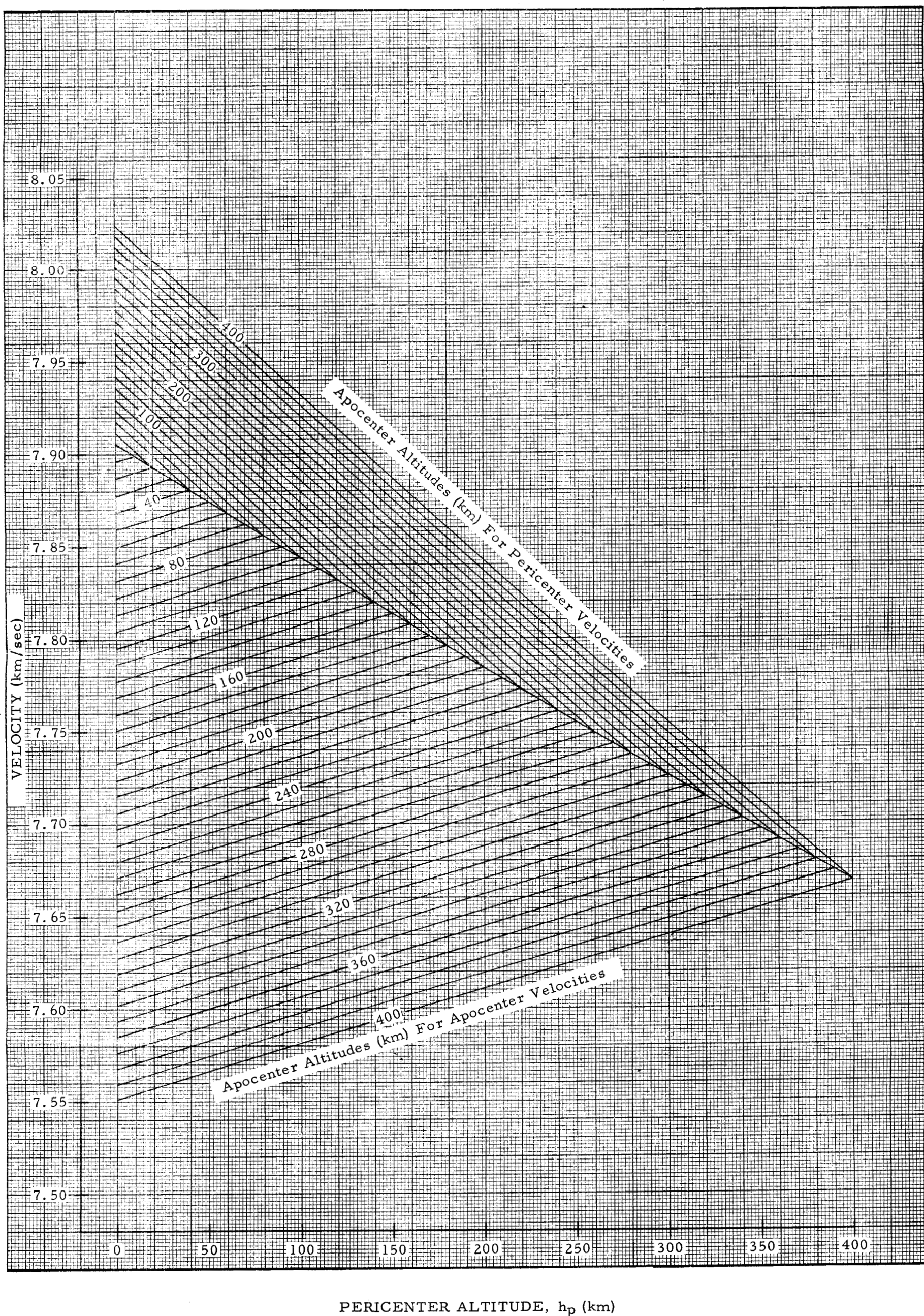
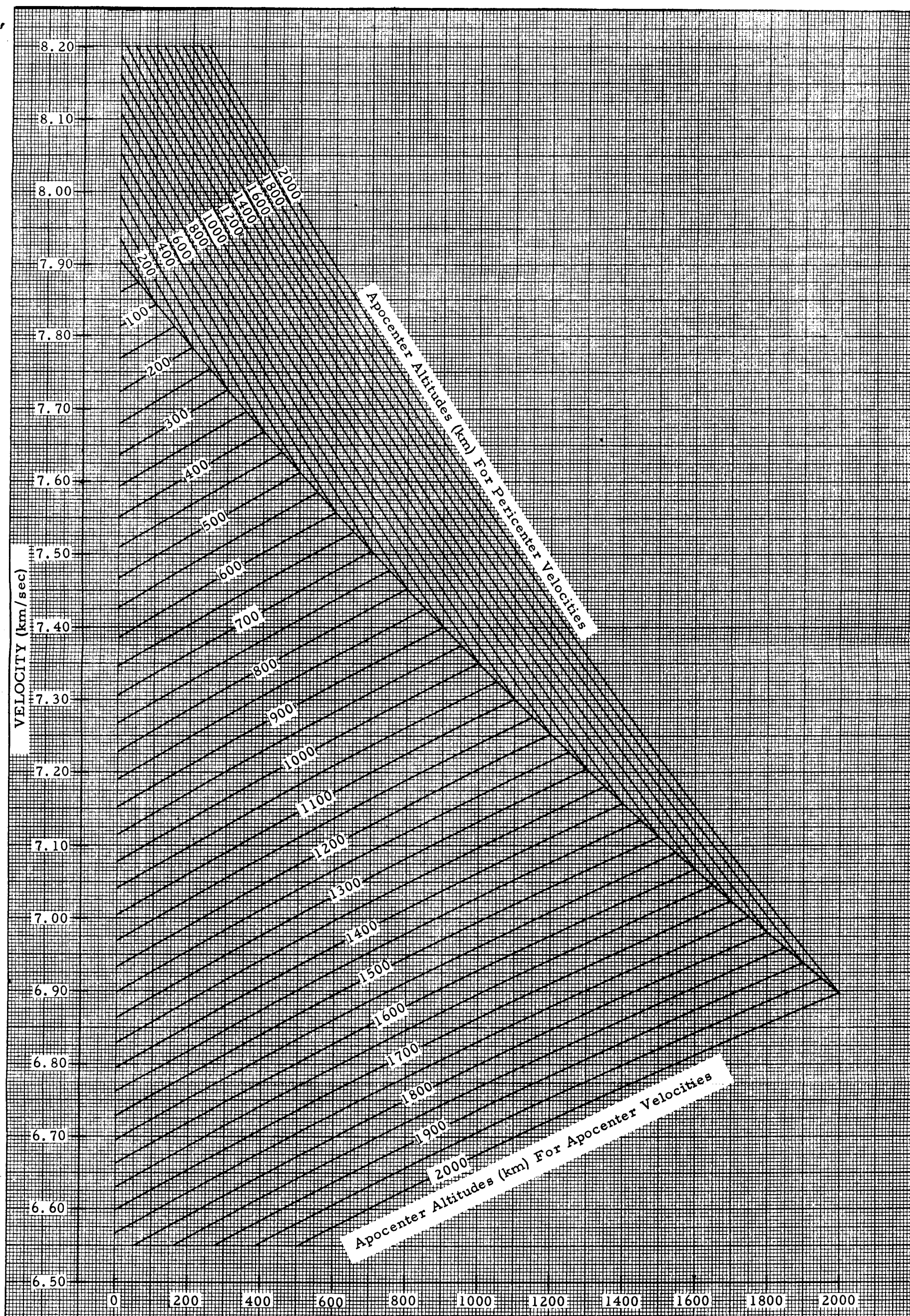


FIGURE 2a. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS





PERICENTER ALTITUDE,  $h_p$  (km)

FIGURE 2b. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



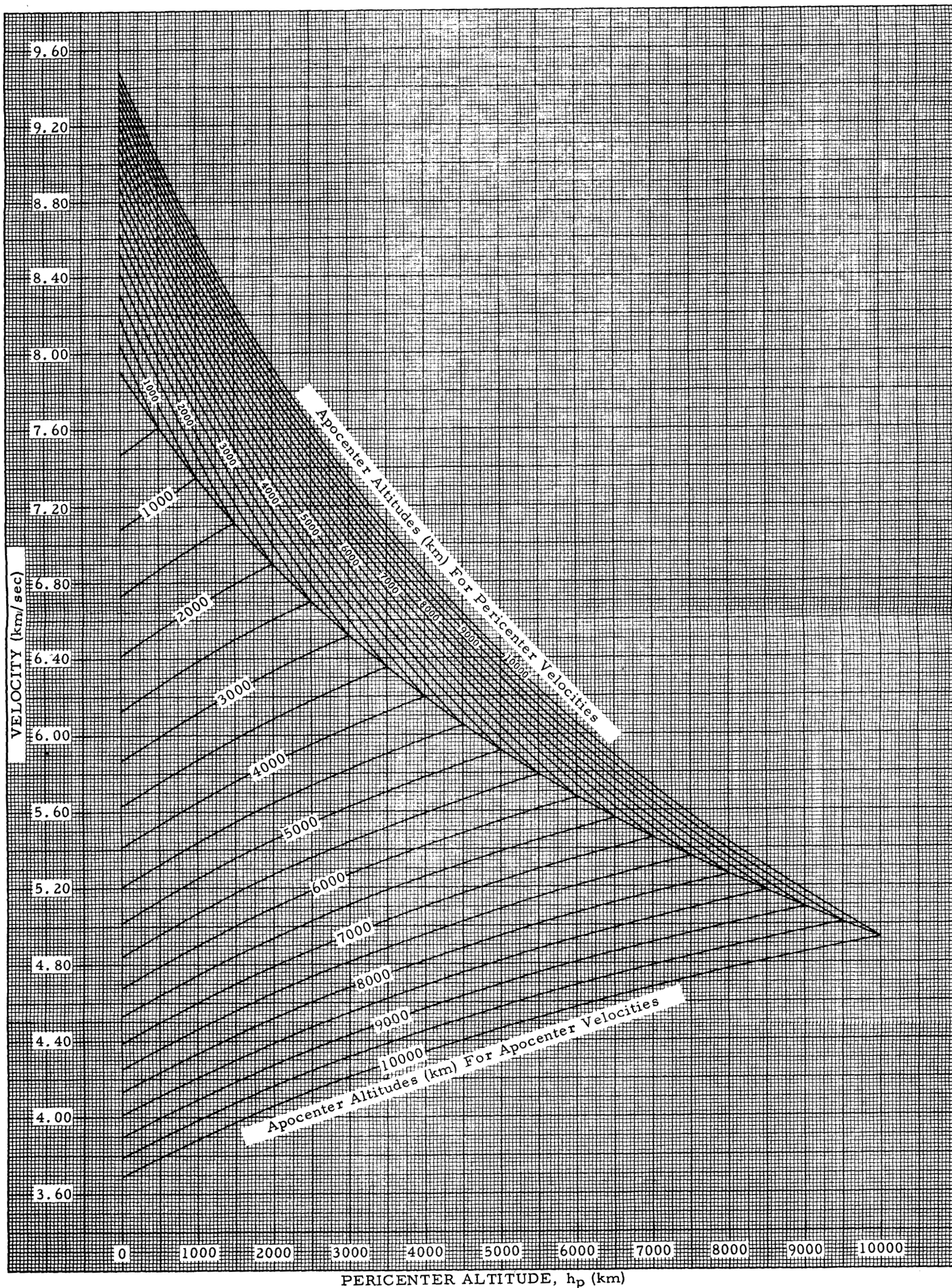


FIGURE 2c. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



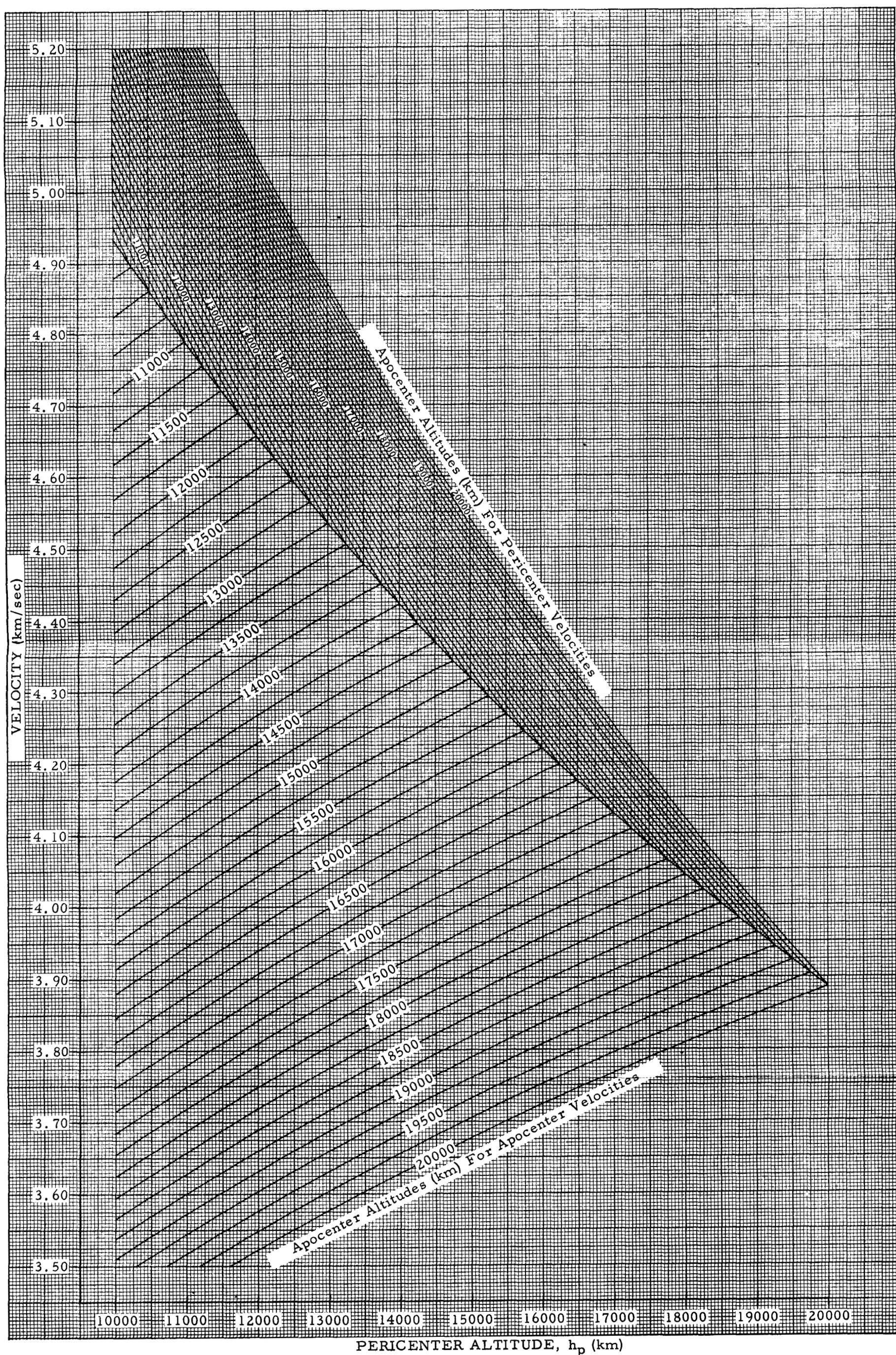


FIGURE 2d. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



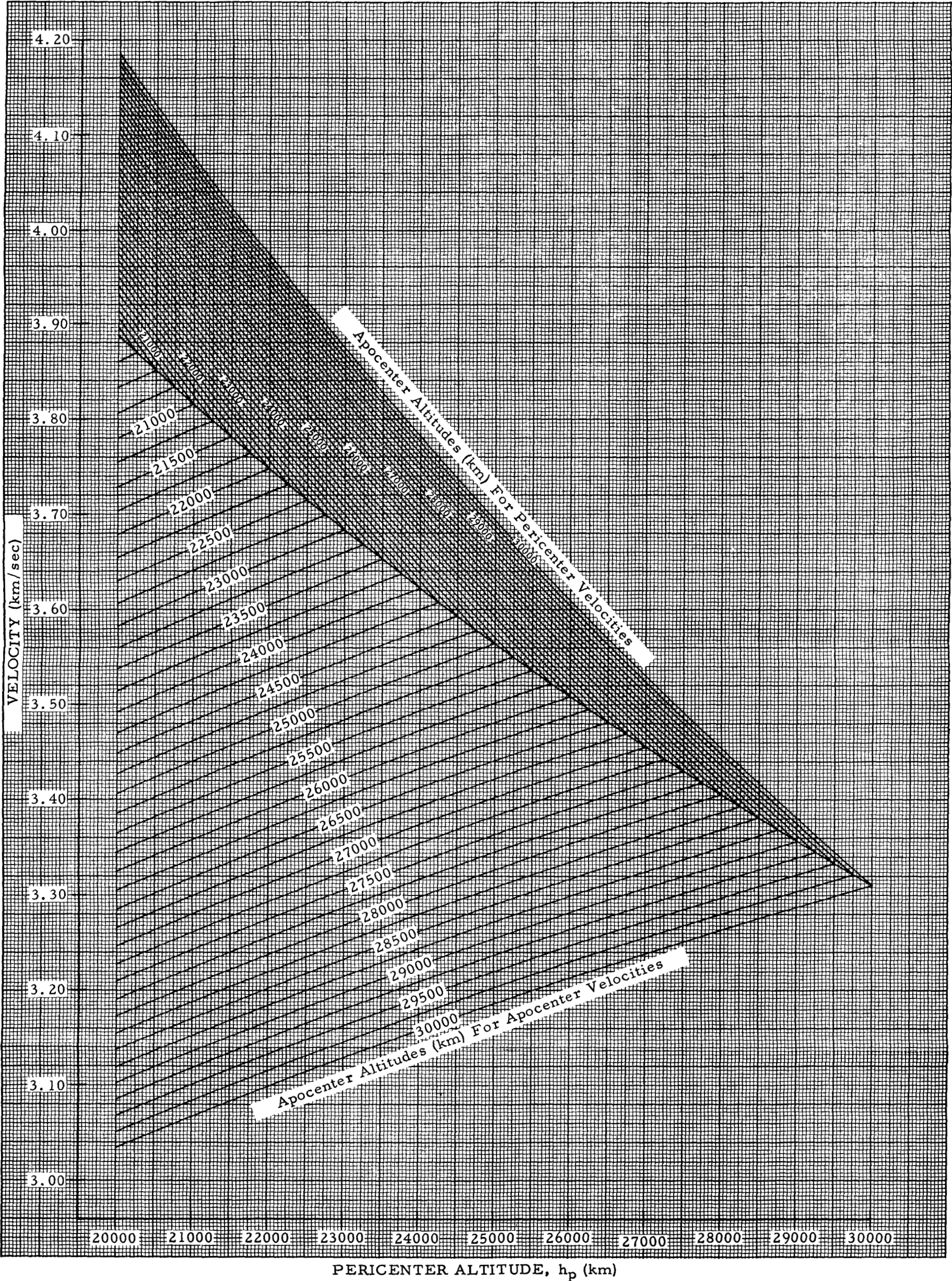


FIGURE 2e. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



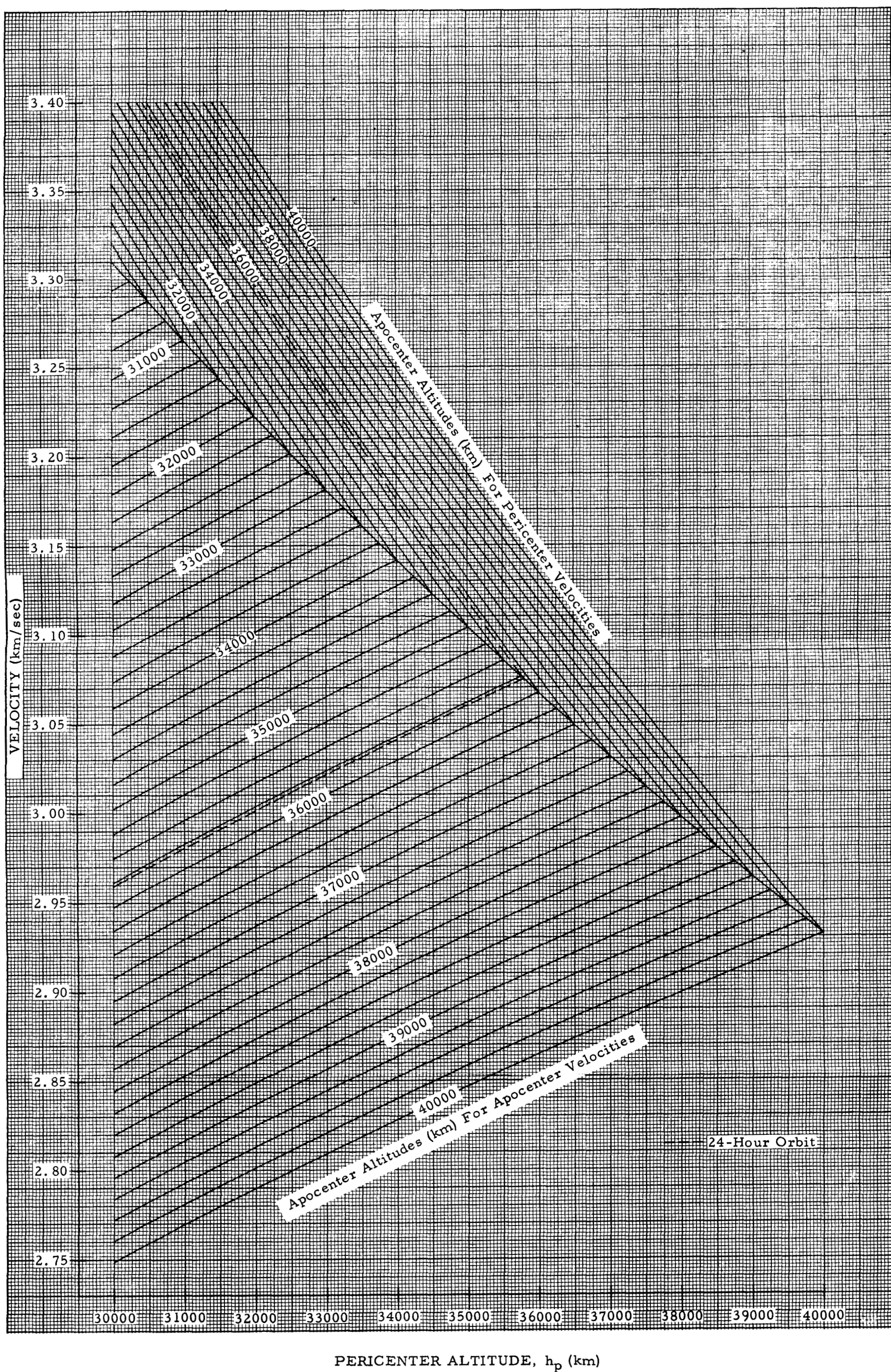


FIGURE 2f. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



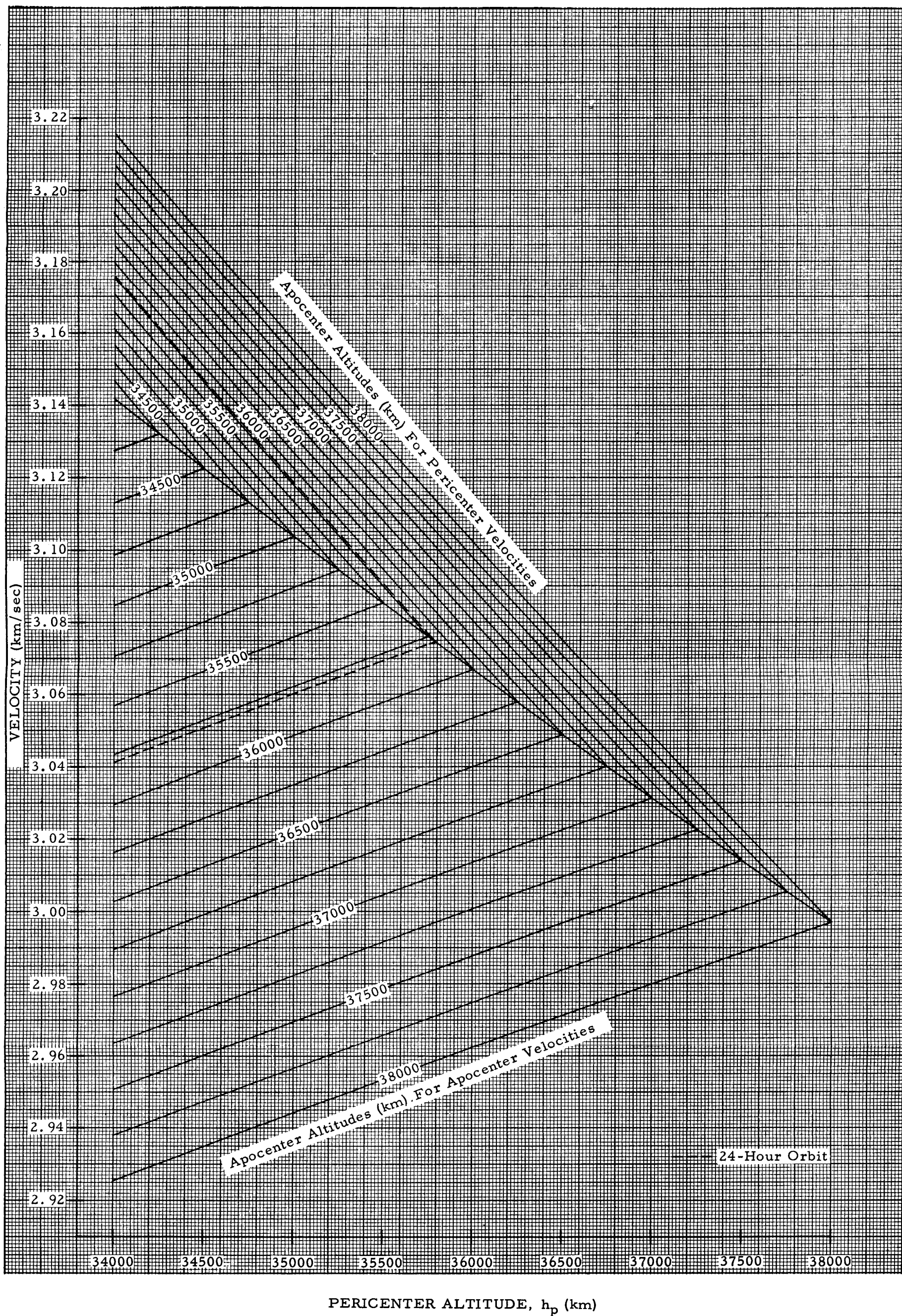


FIGURE 2g. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



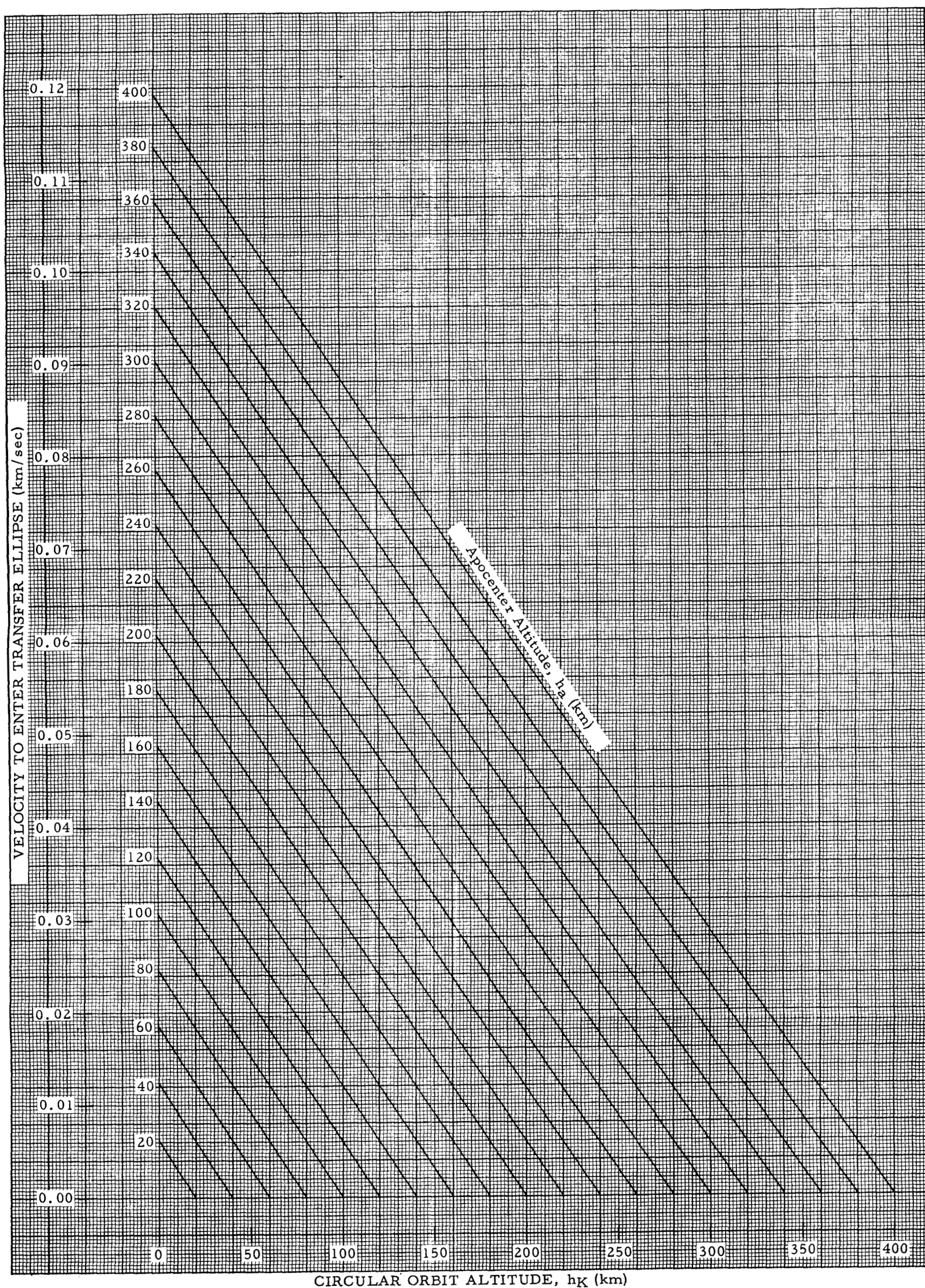


FIGURE 3a. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



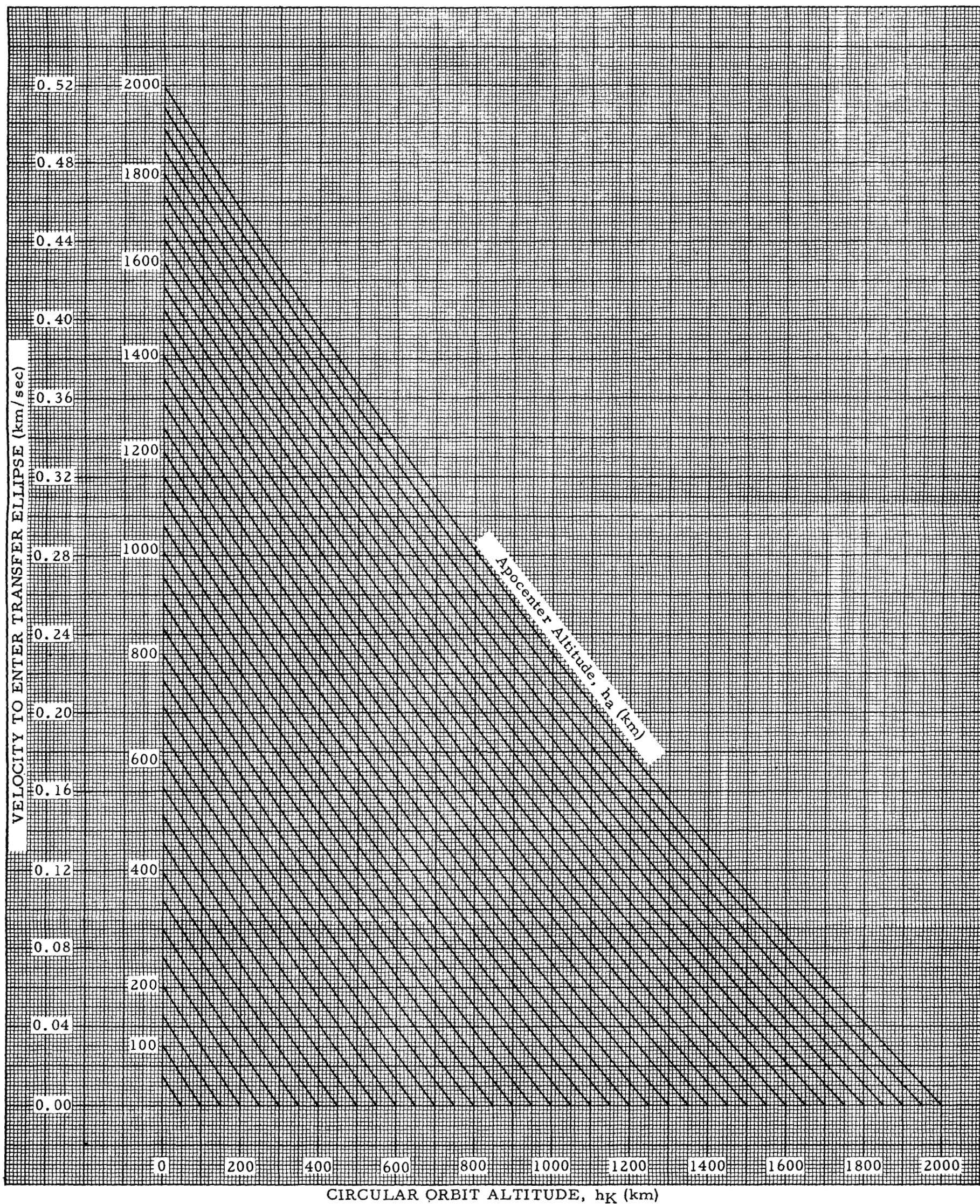


FIGURE 3b. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT  
VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



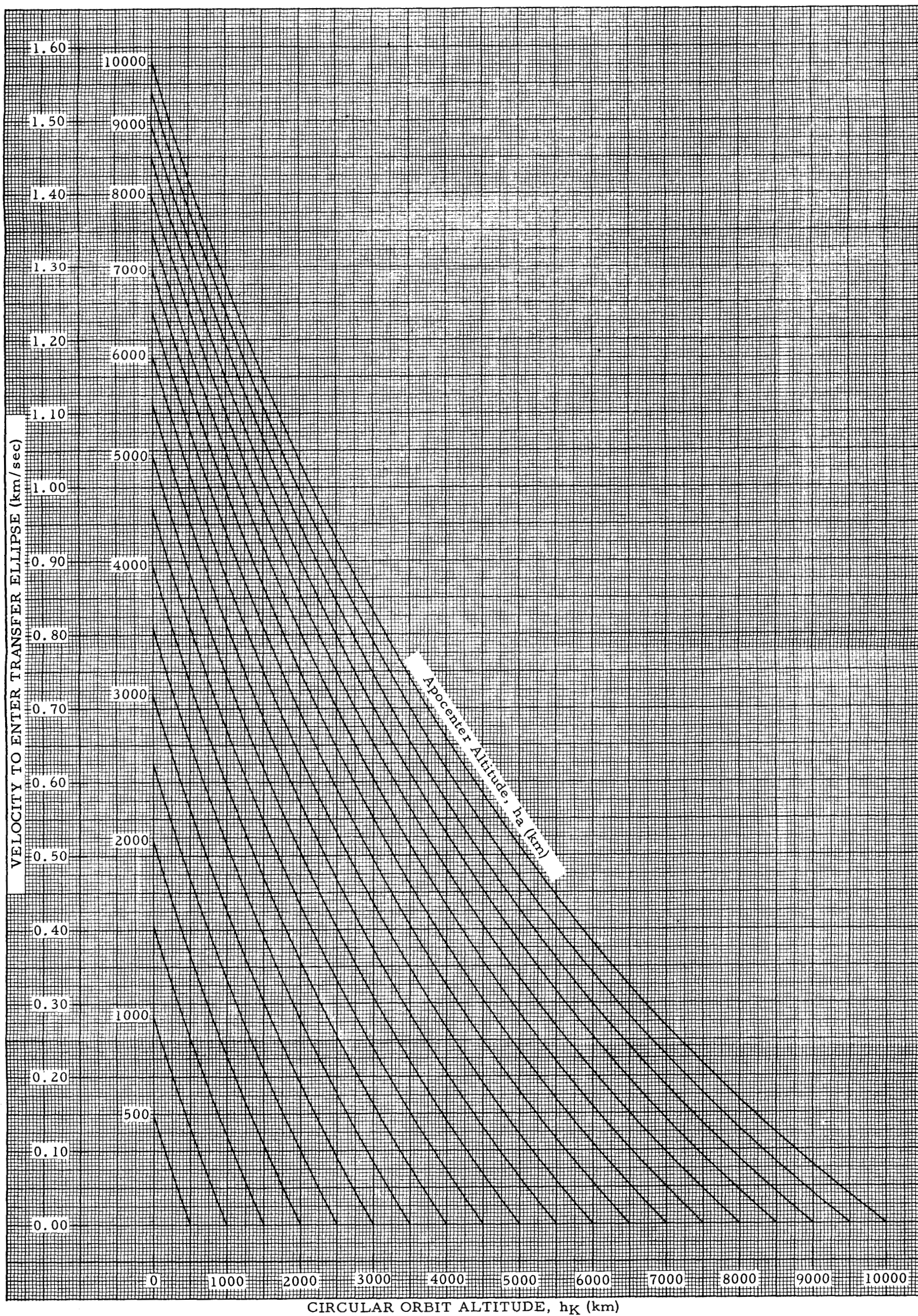


FIGURE 3c. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



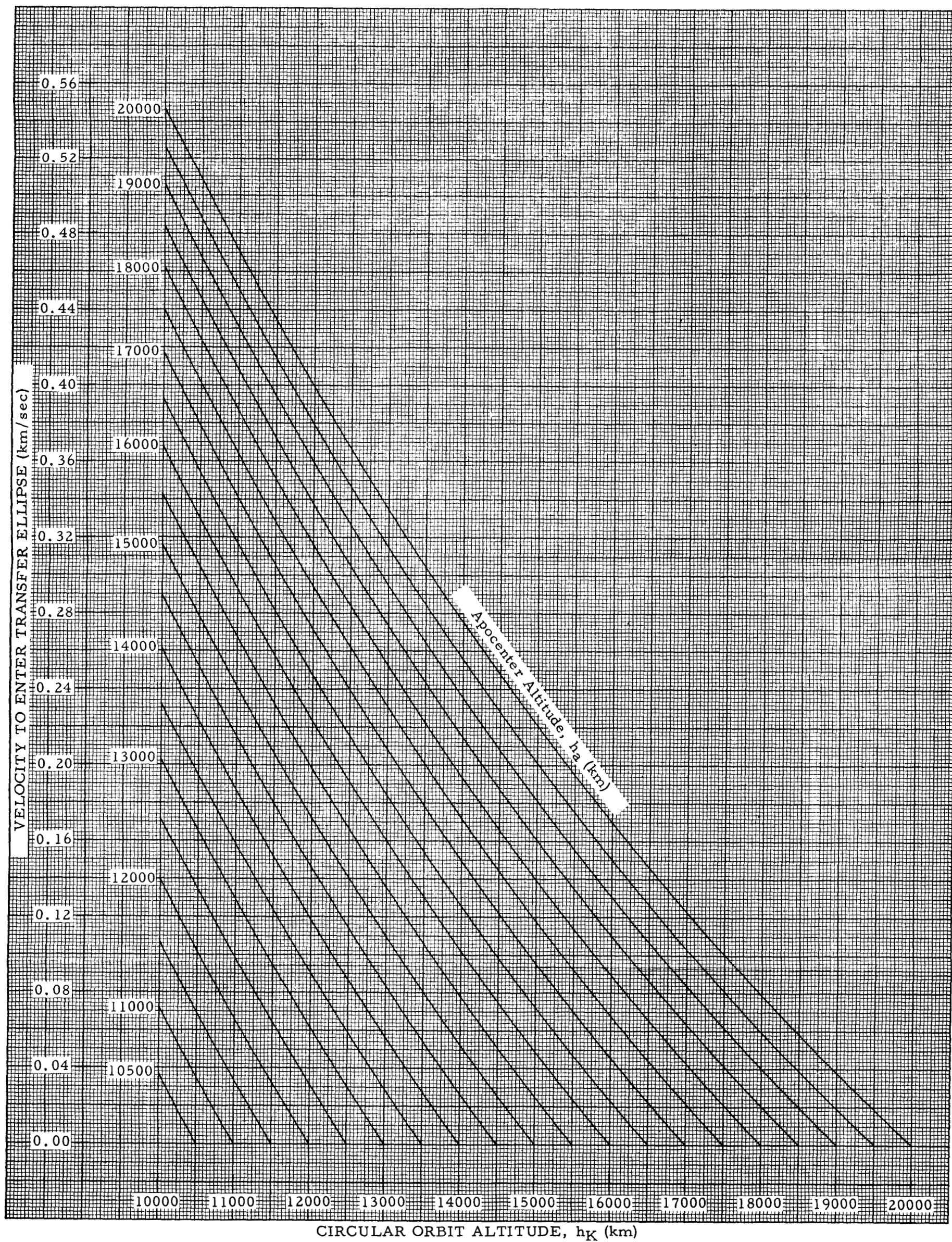


FIGURE 3d. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



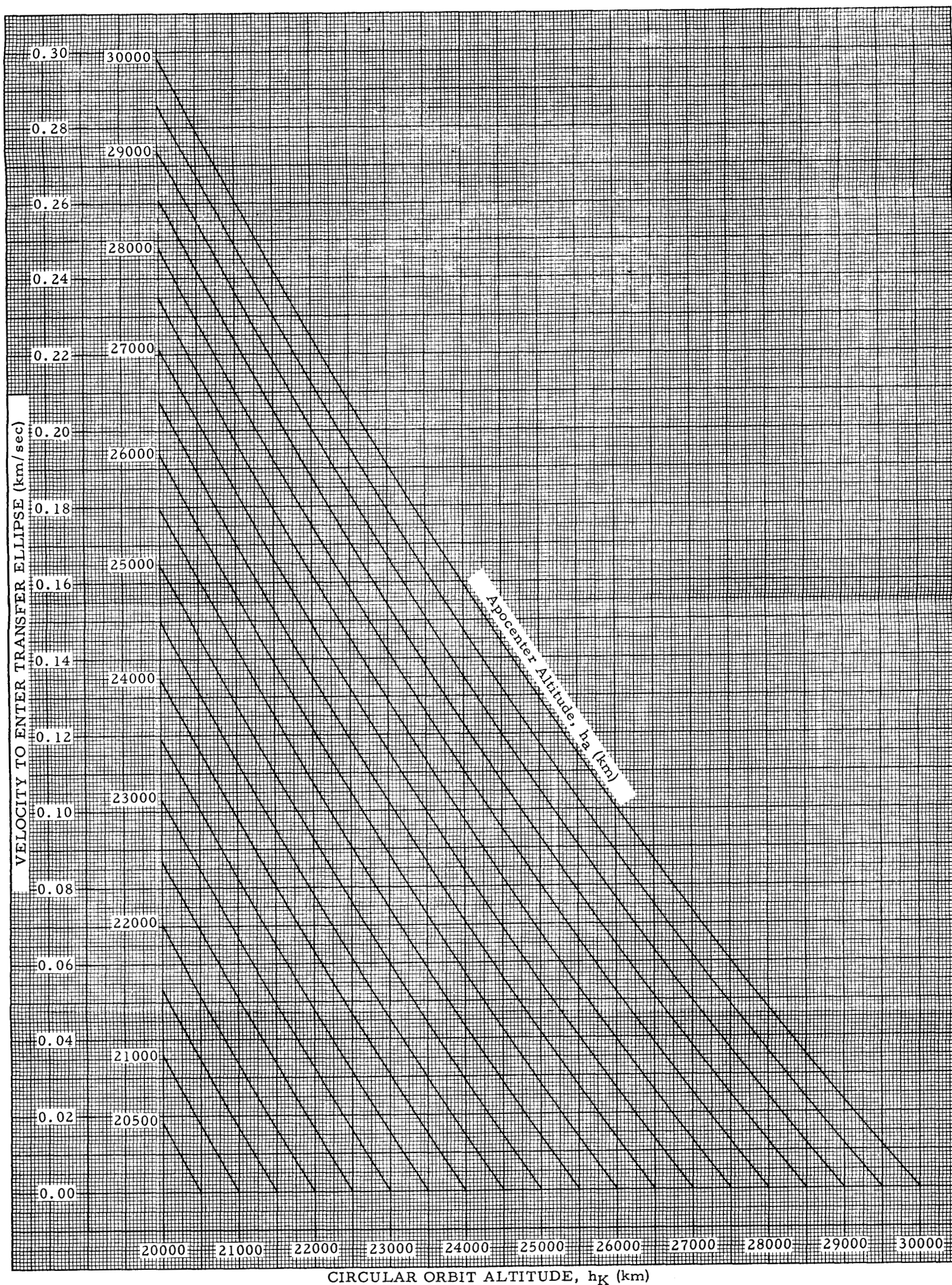


FIGURE 3e. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



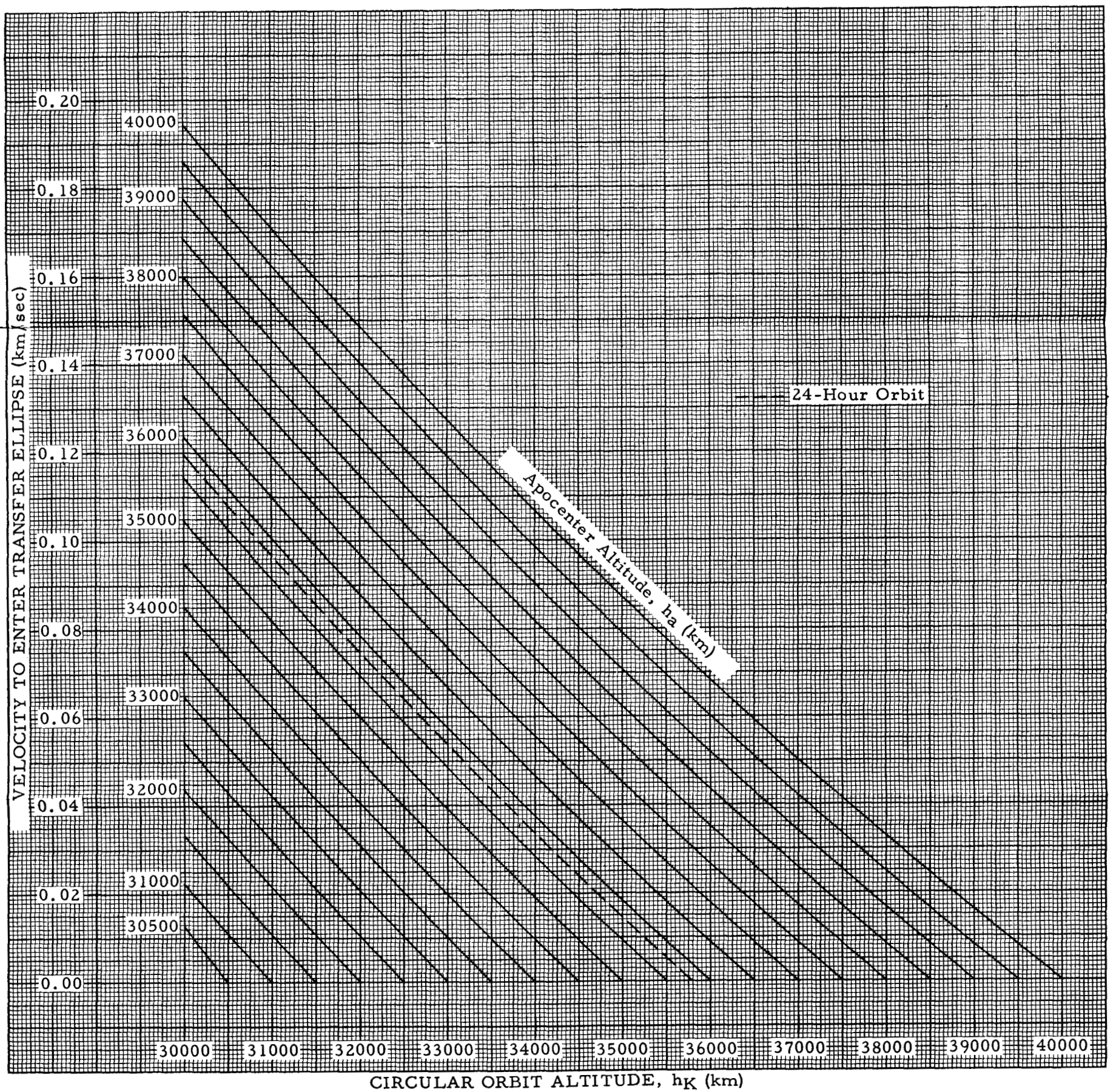


FIGURE 3f. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



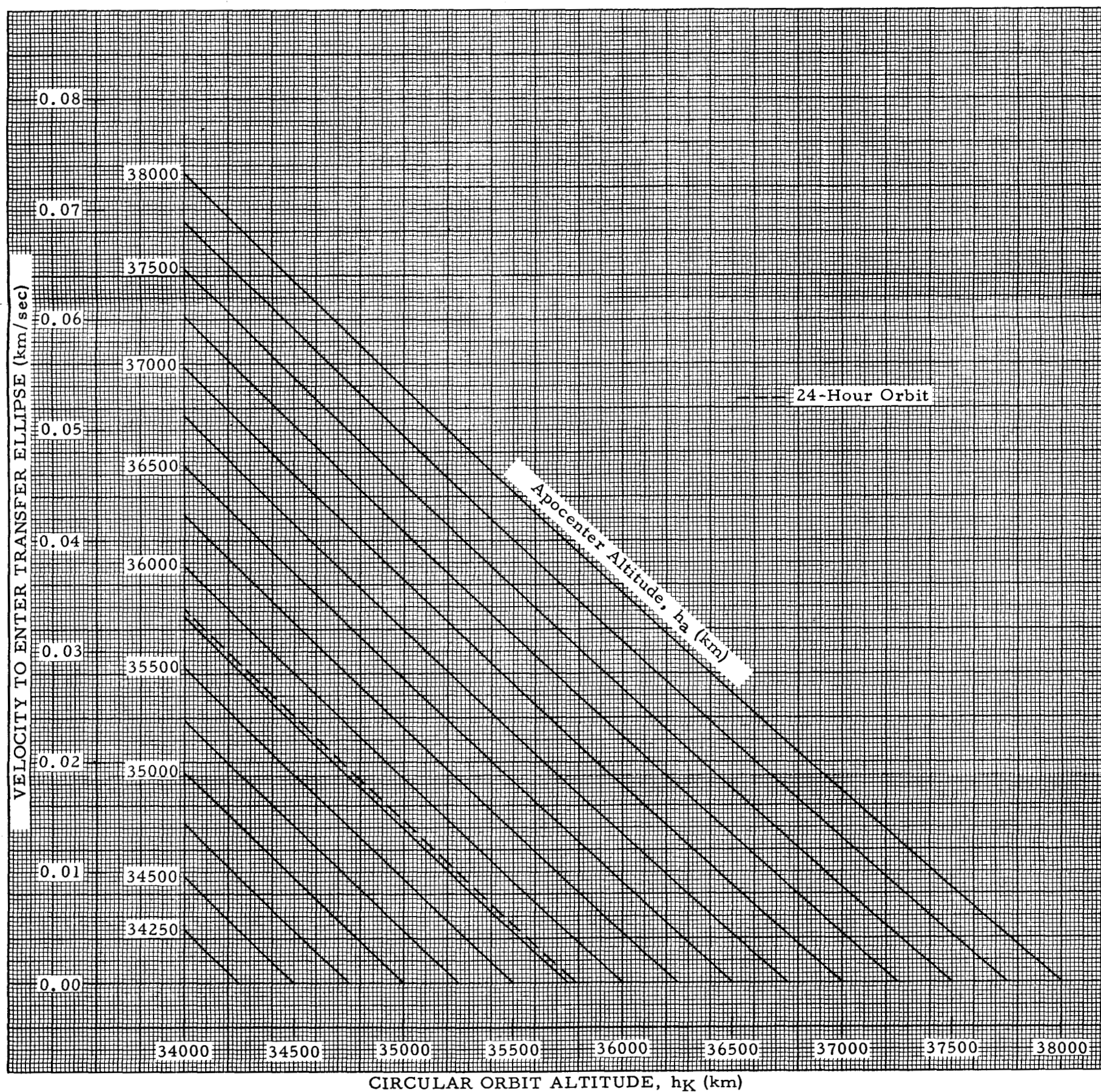


FIGURE 3g. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



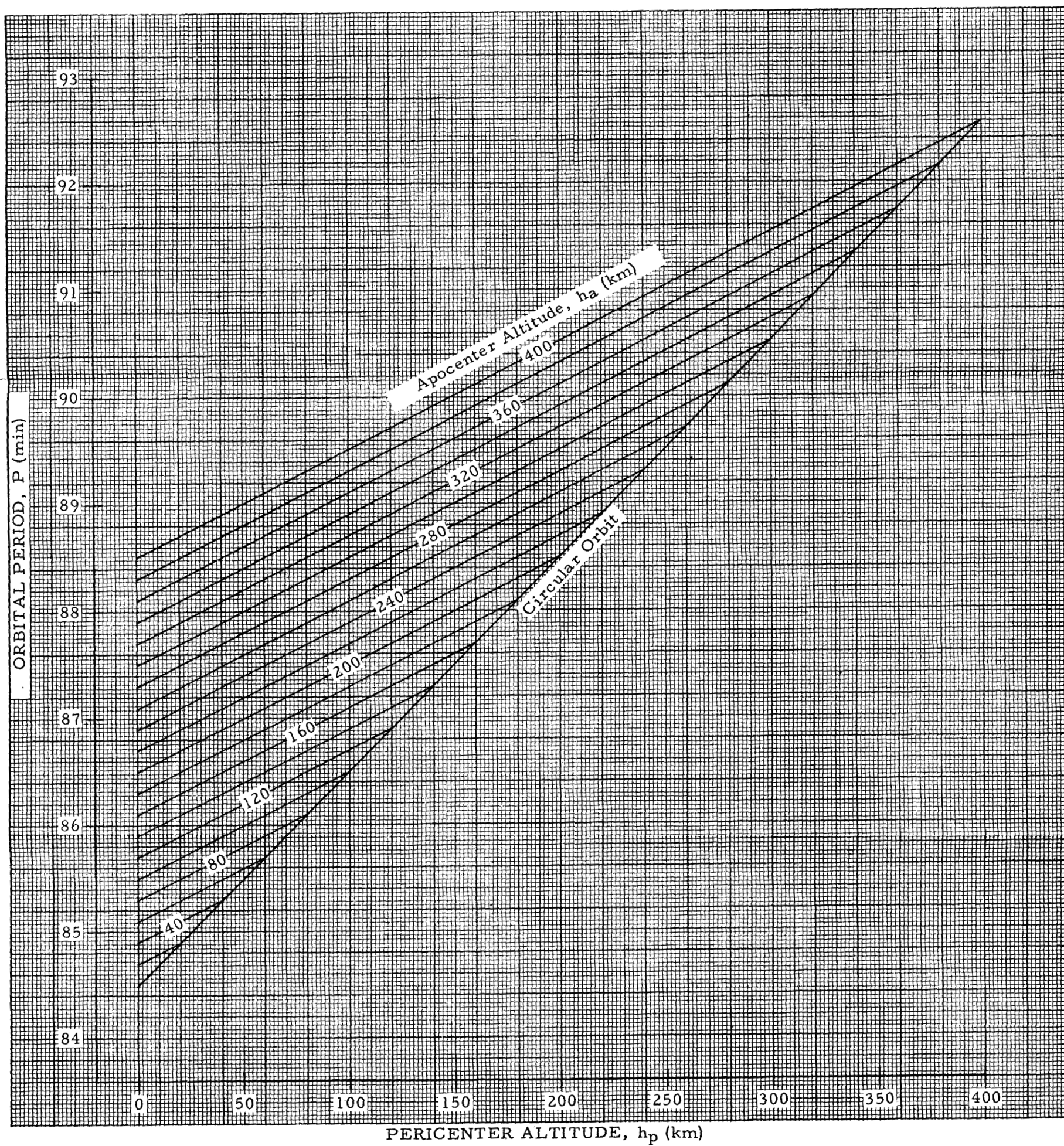


FIGURE 4a. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



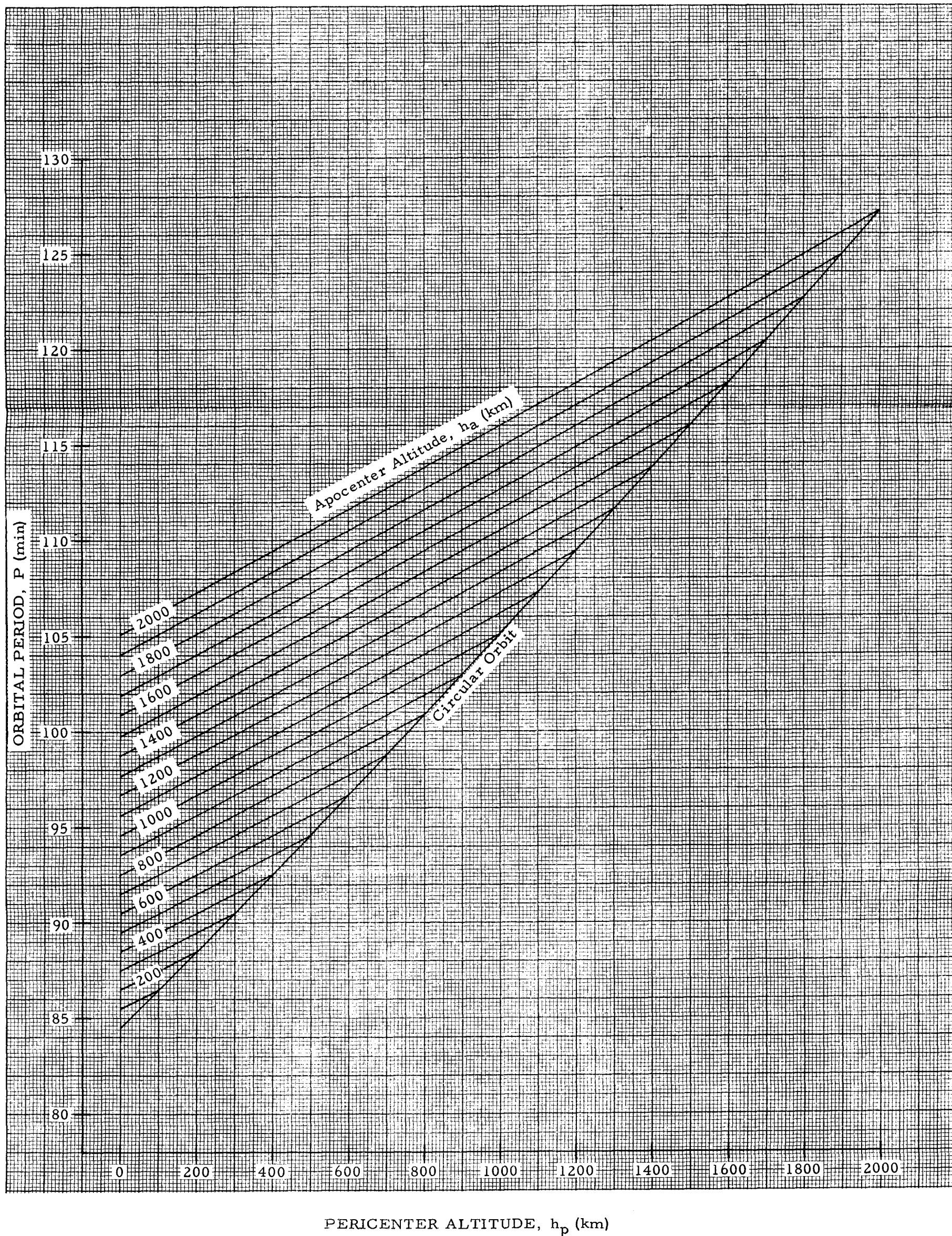


FIGURE 4b. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



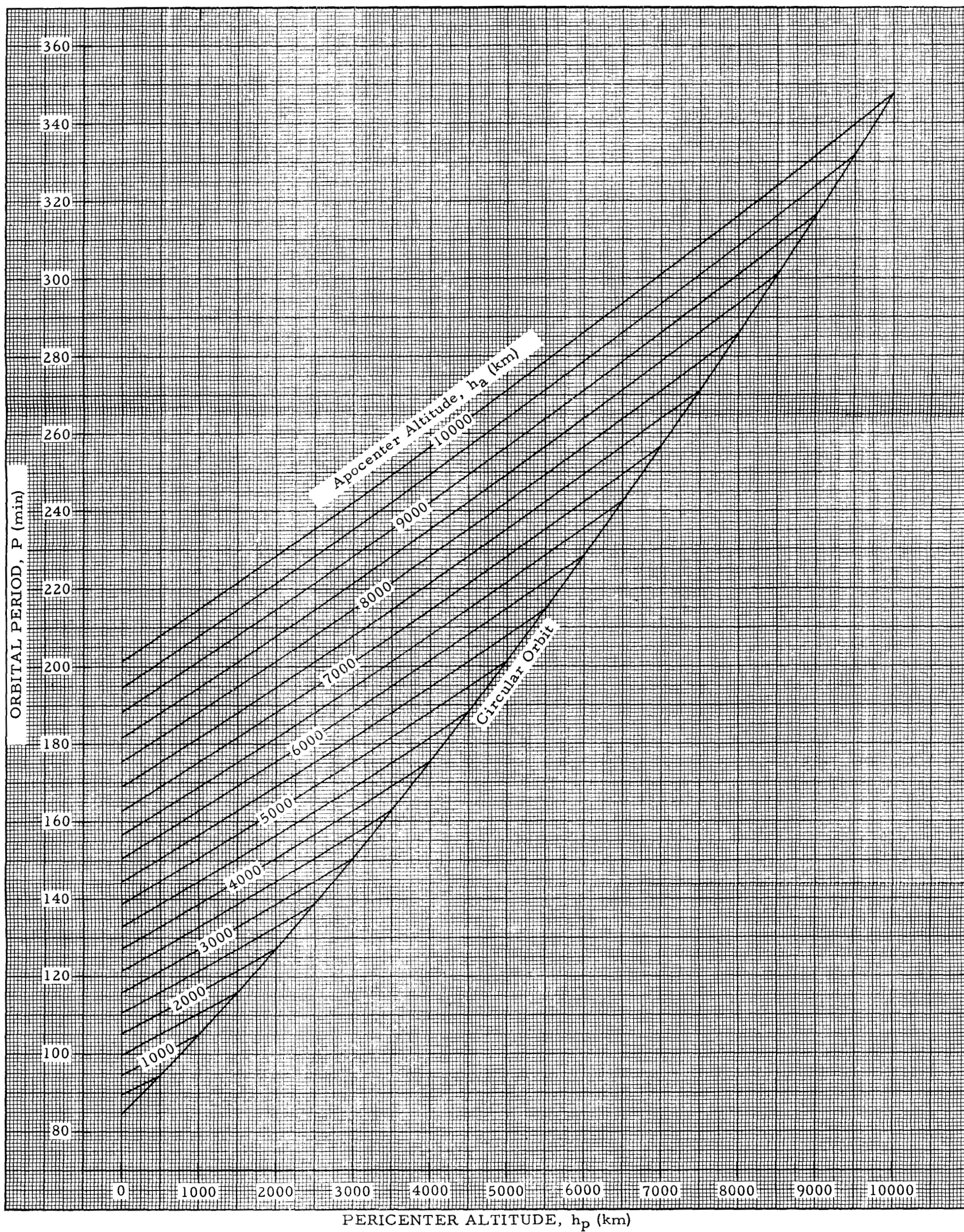


FIGURE 4c. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



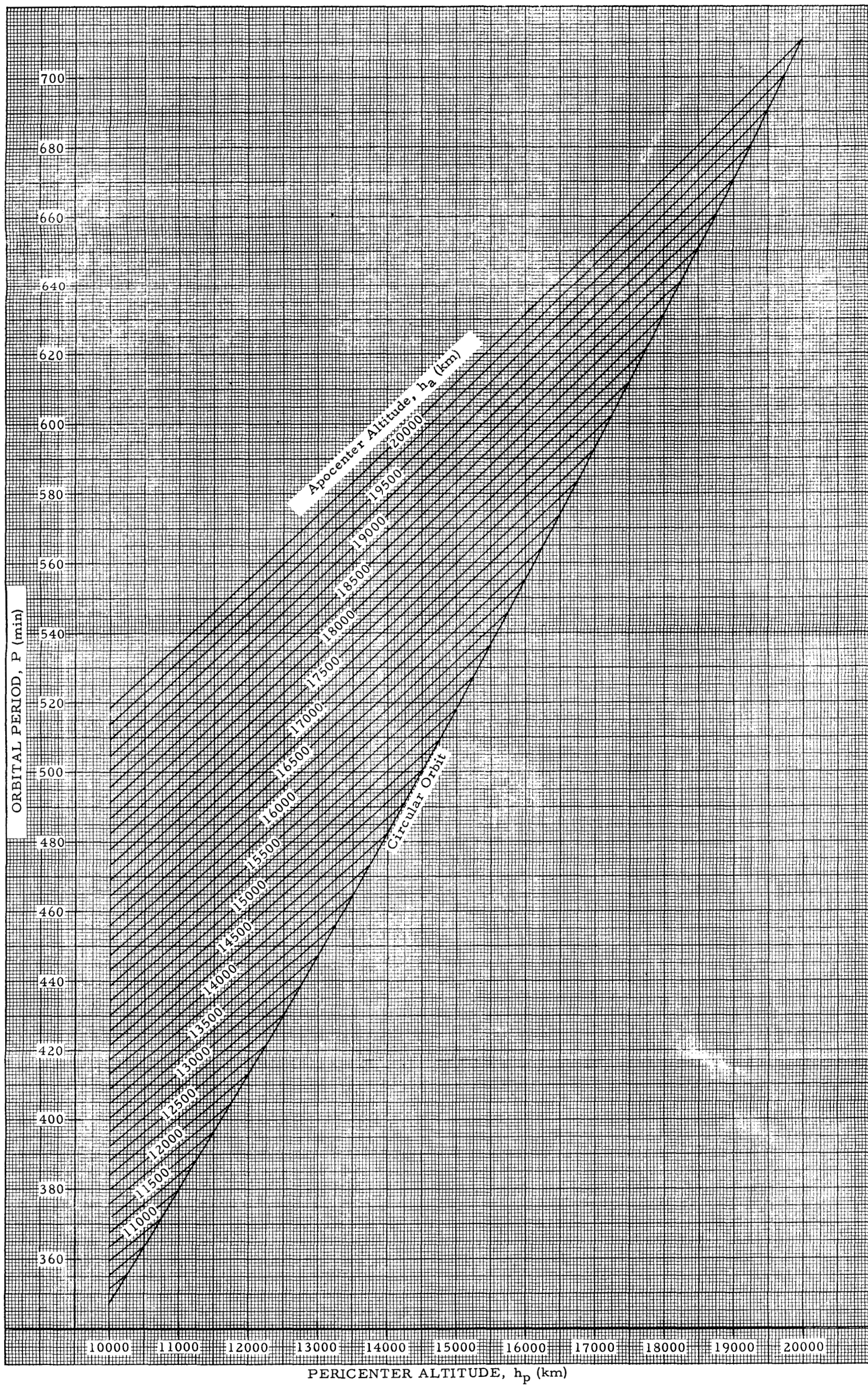


FIGURE 4d. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



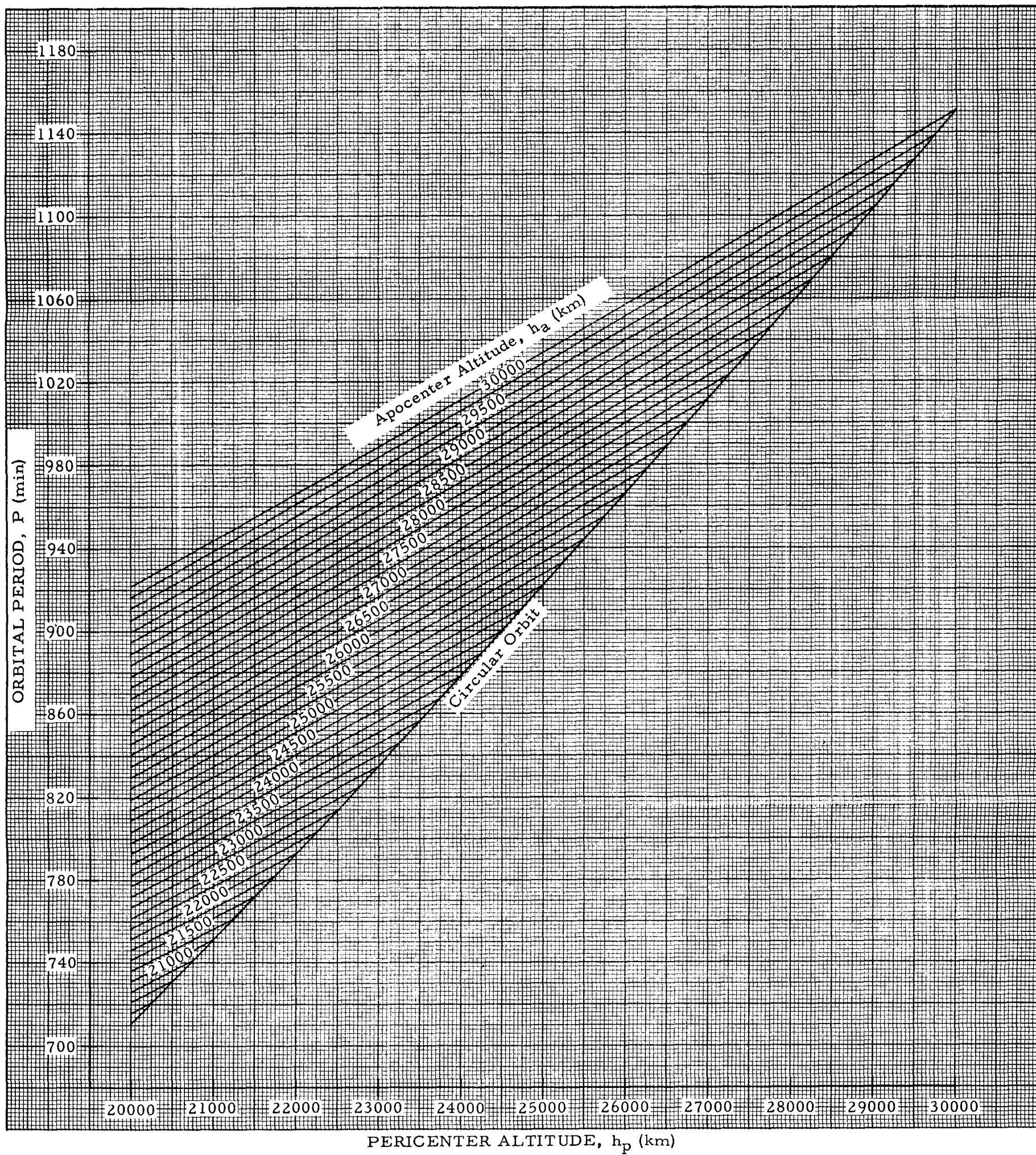


FIGURE 4e. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



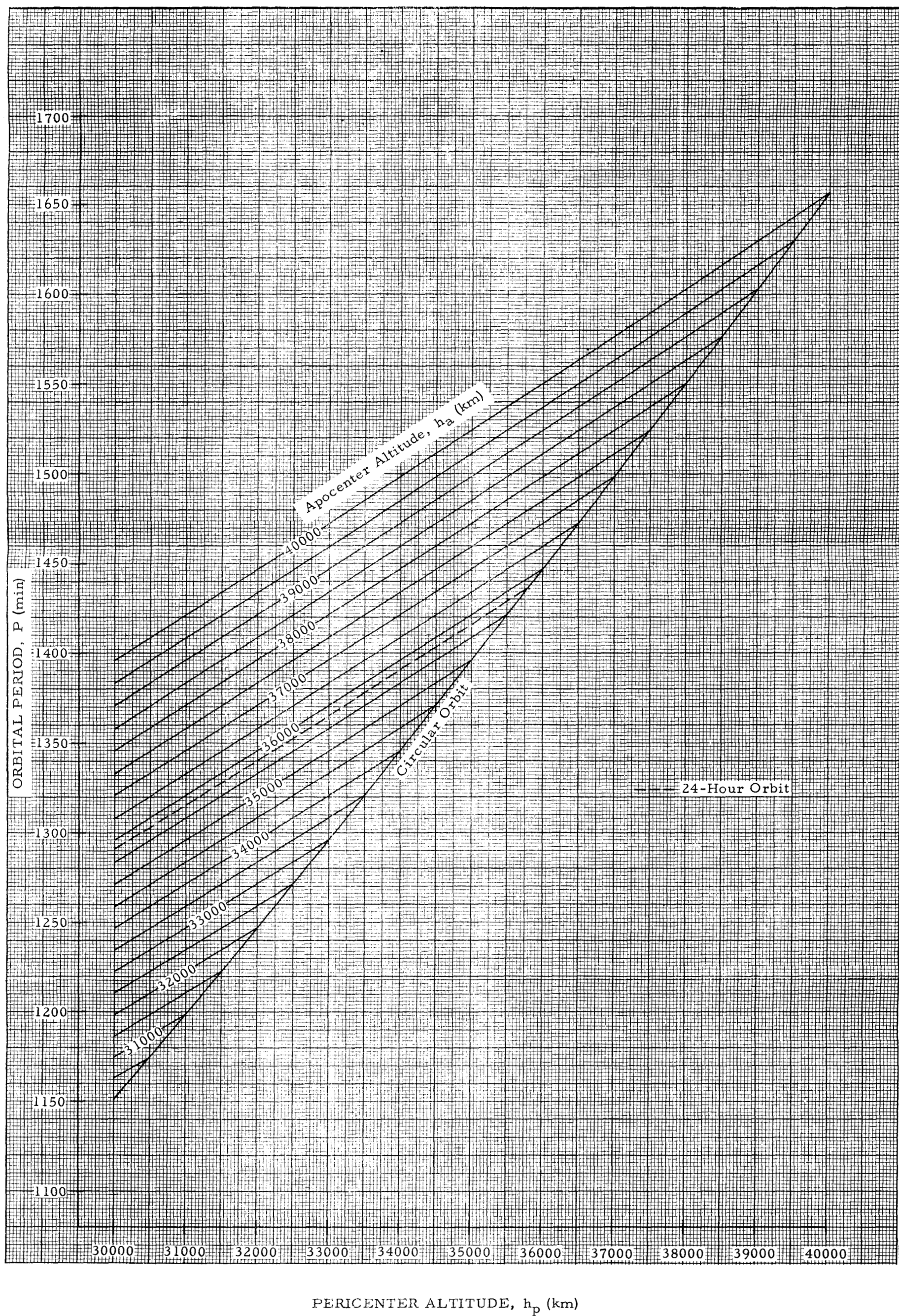


FIGURE 4f. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



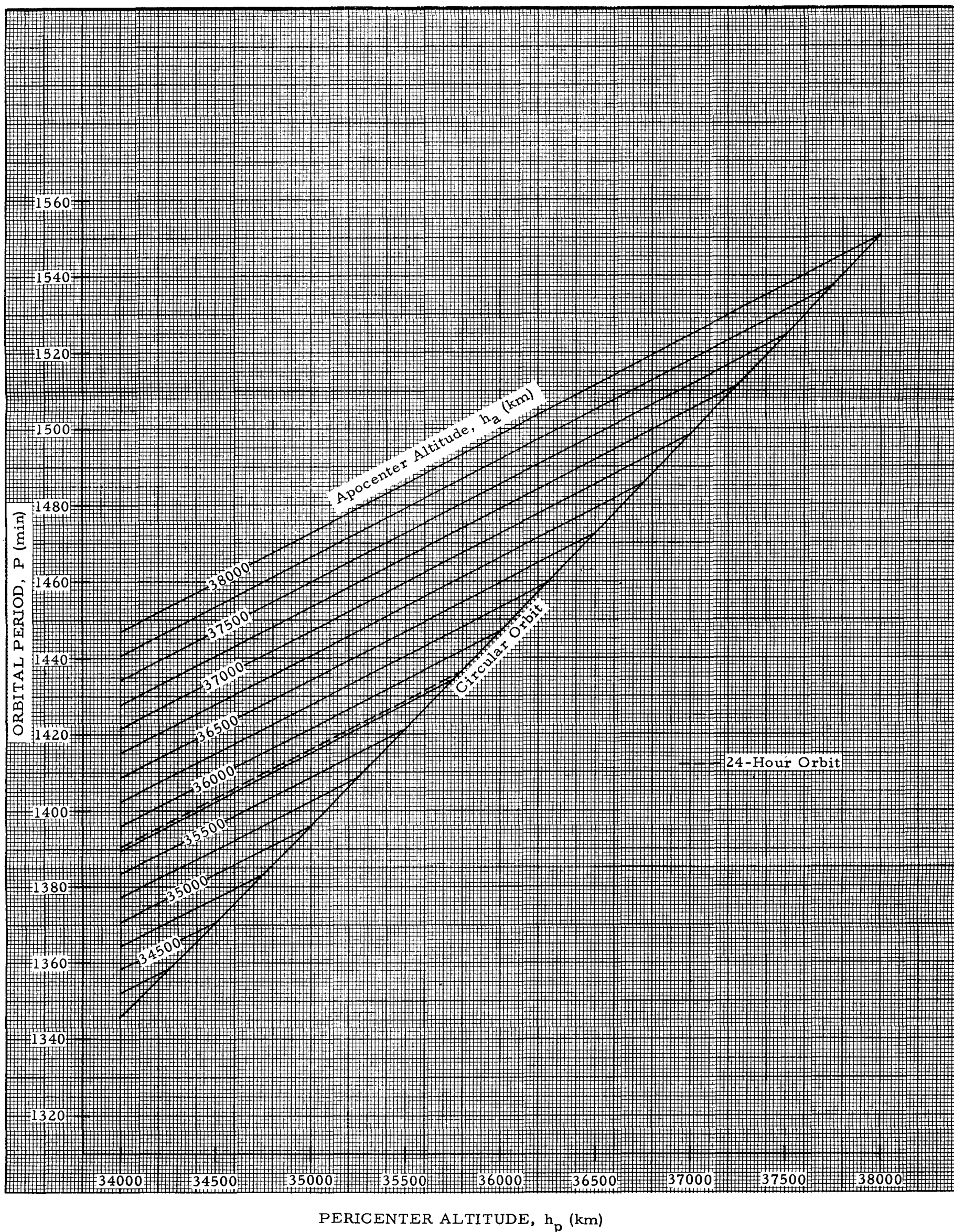


FIGURE 4g. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

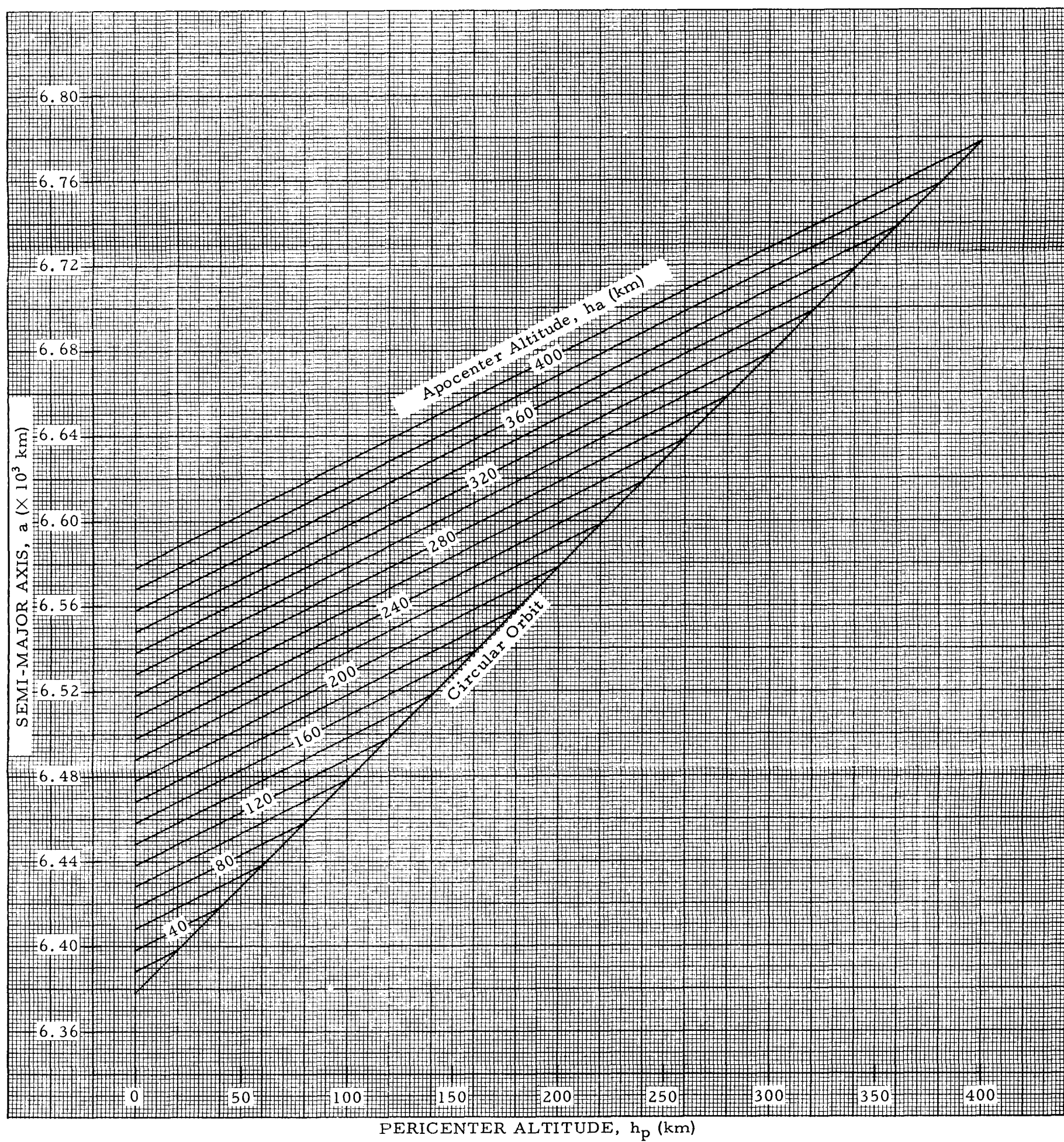


FIGURE 5a. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



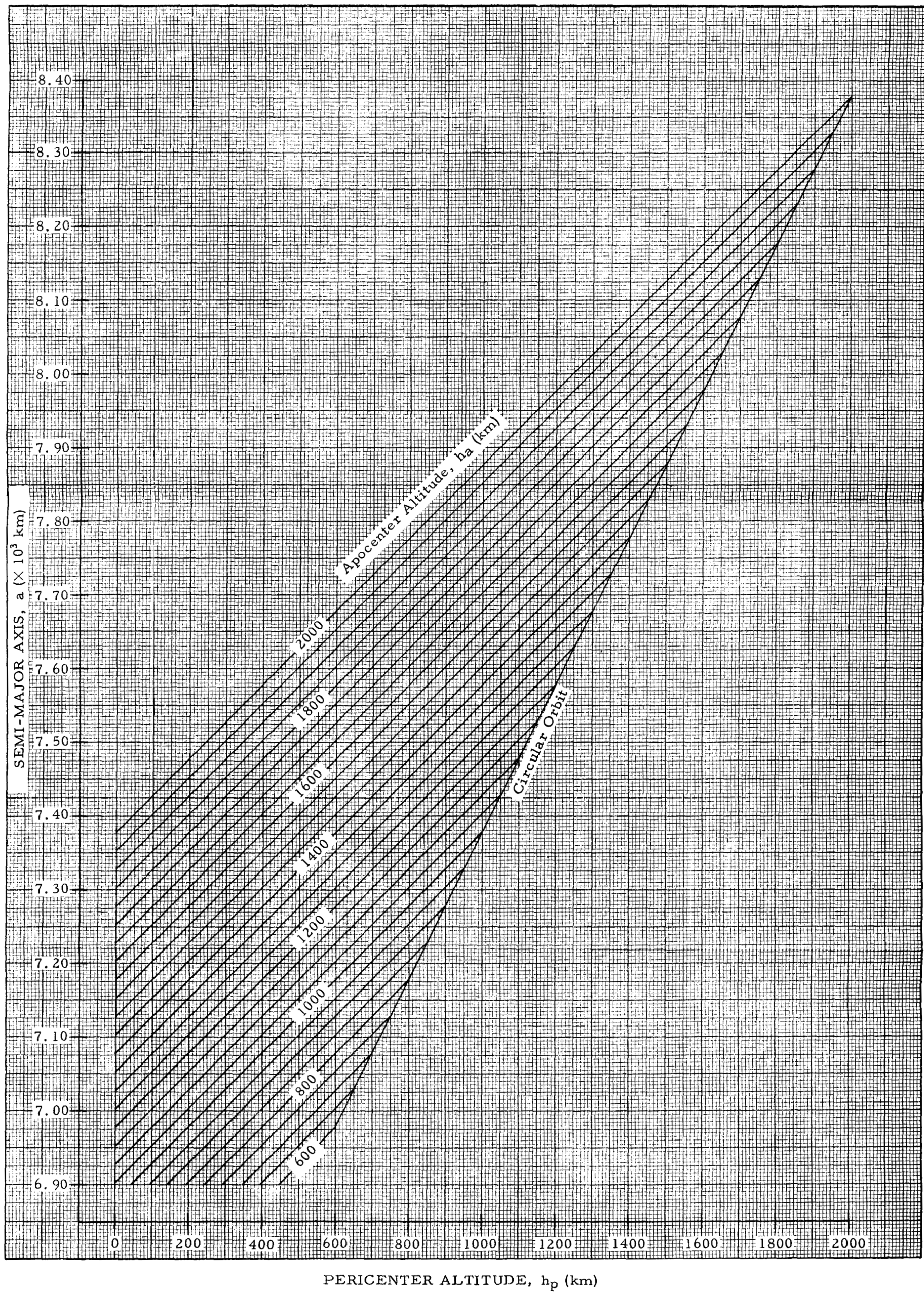


FIGURE 5b. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



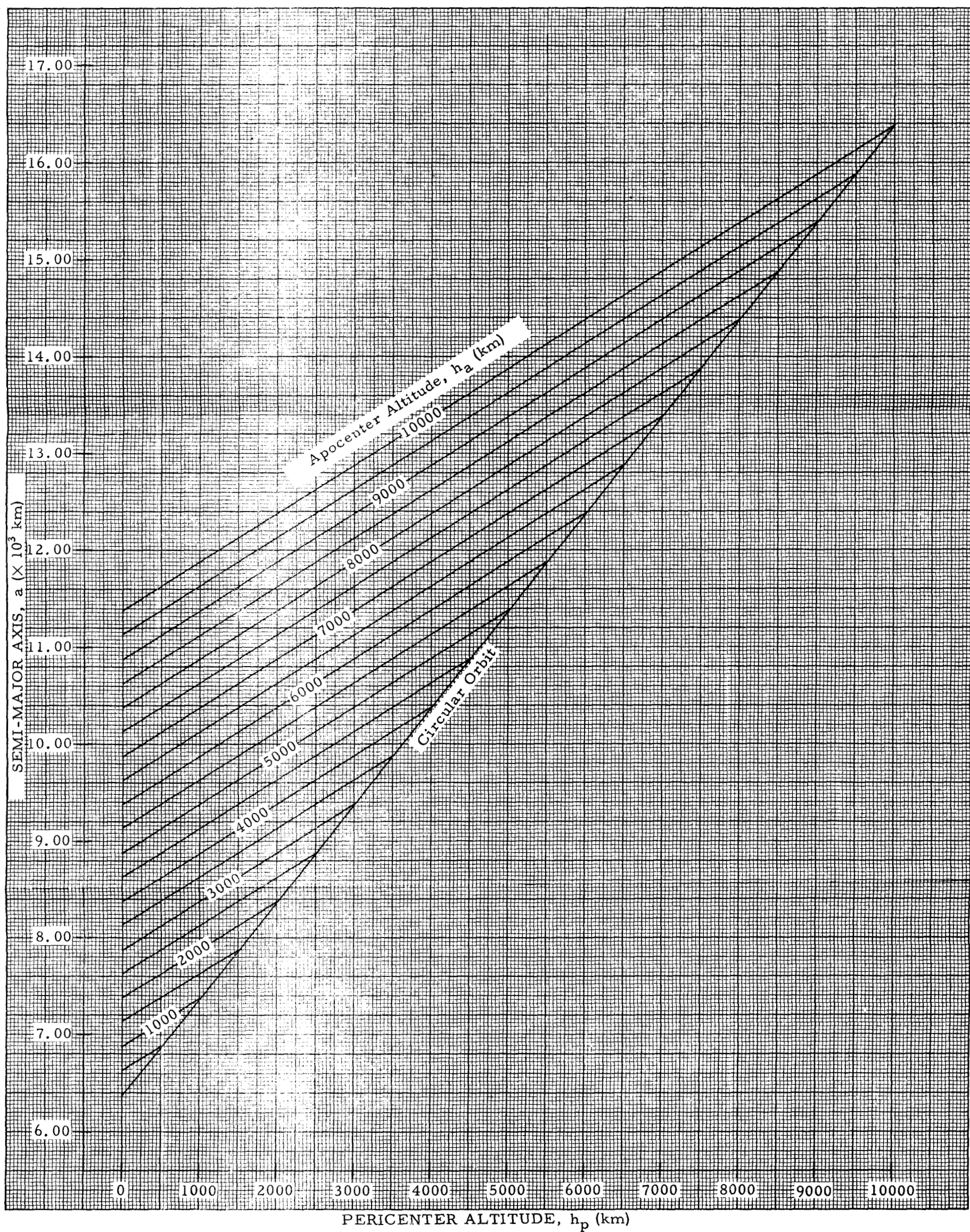


FIGURE 5c. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



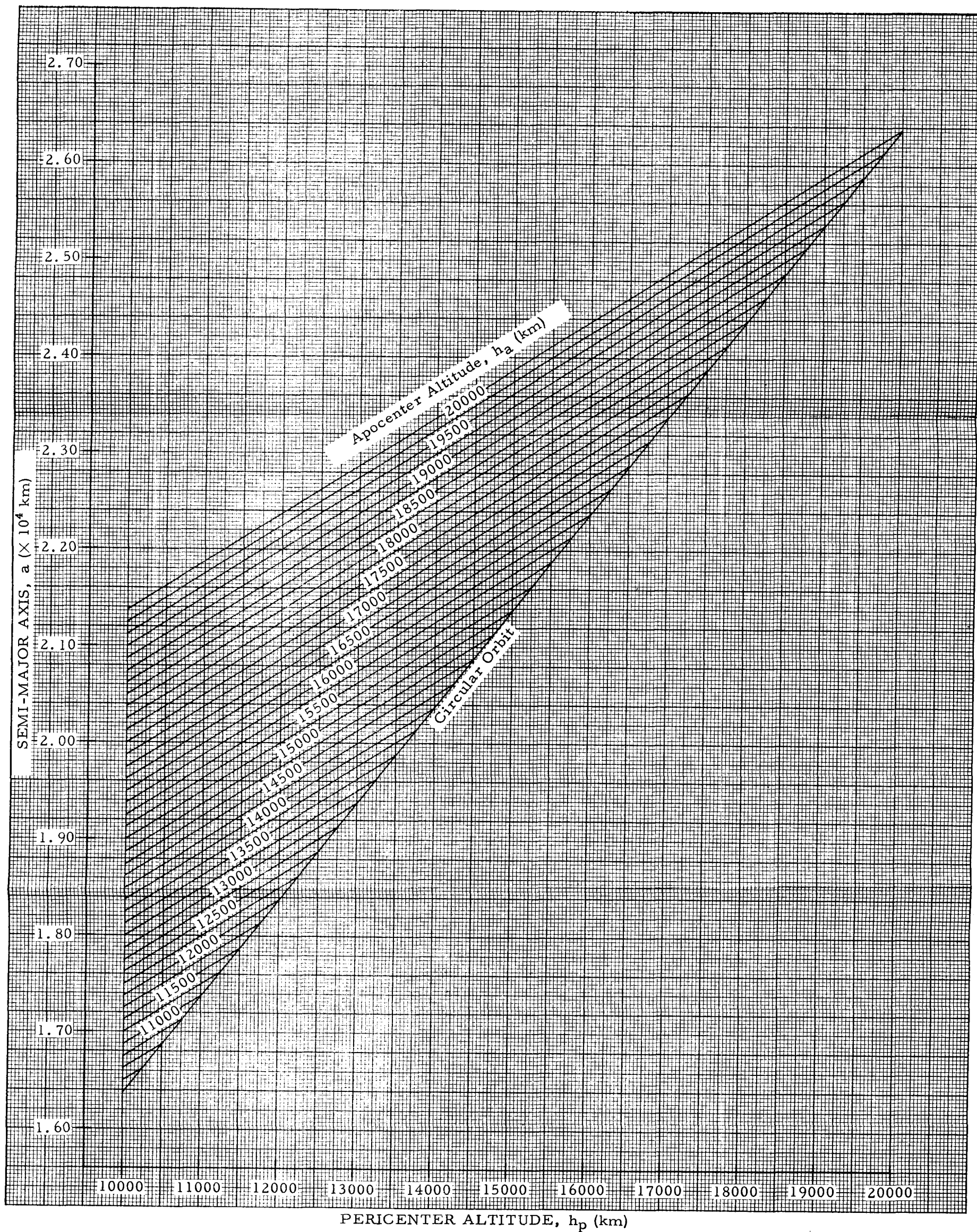


FIGURE 5d. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



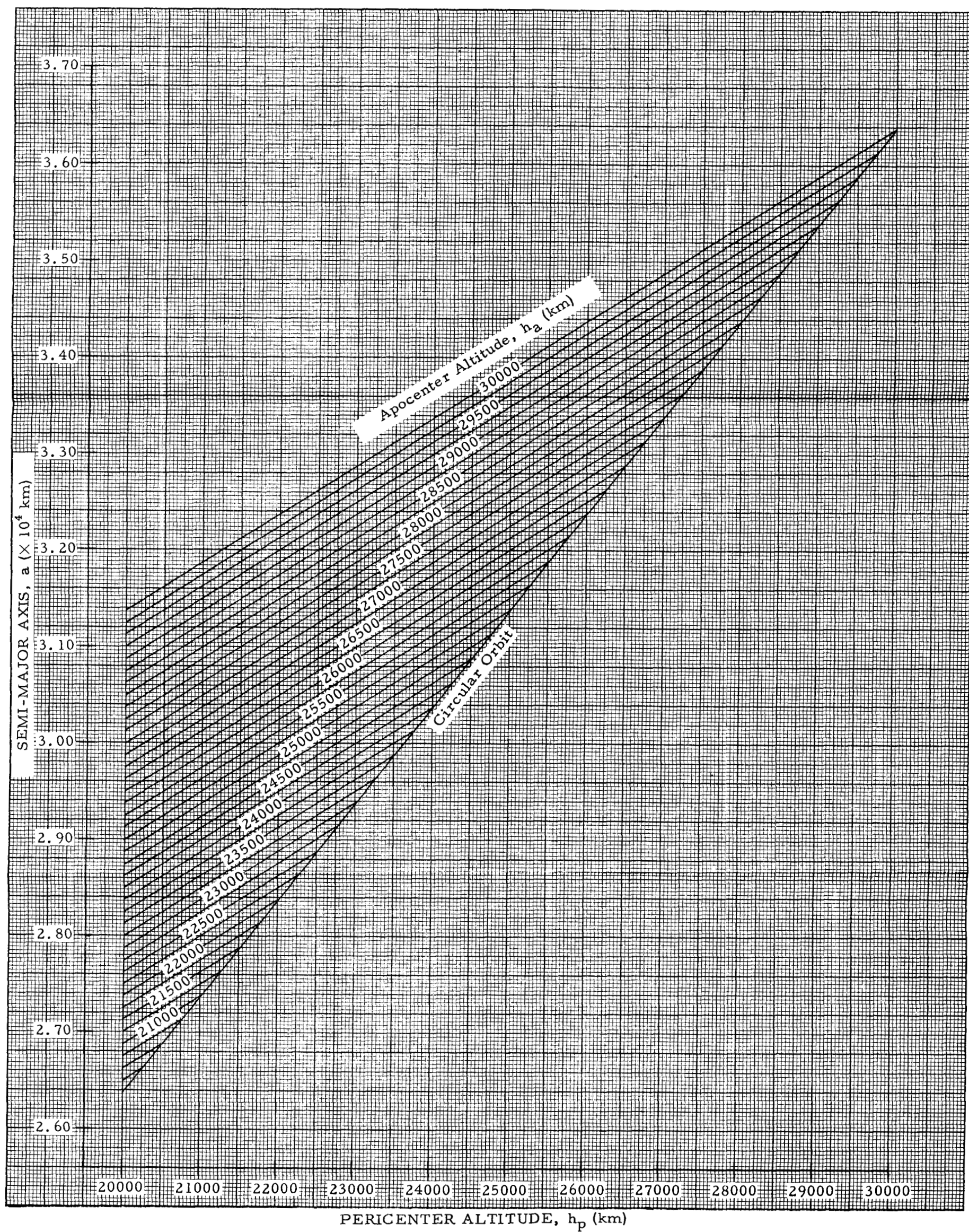


FIGURE 5e. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



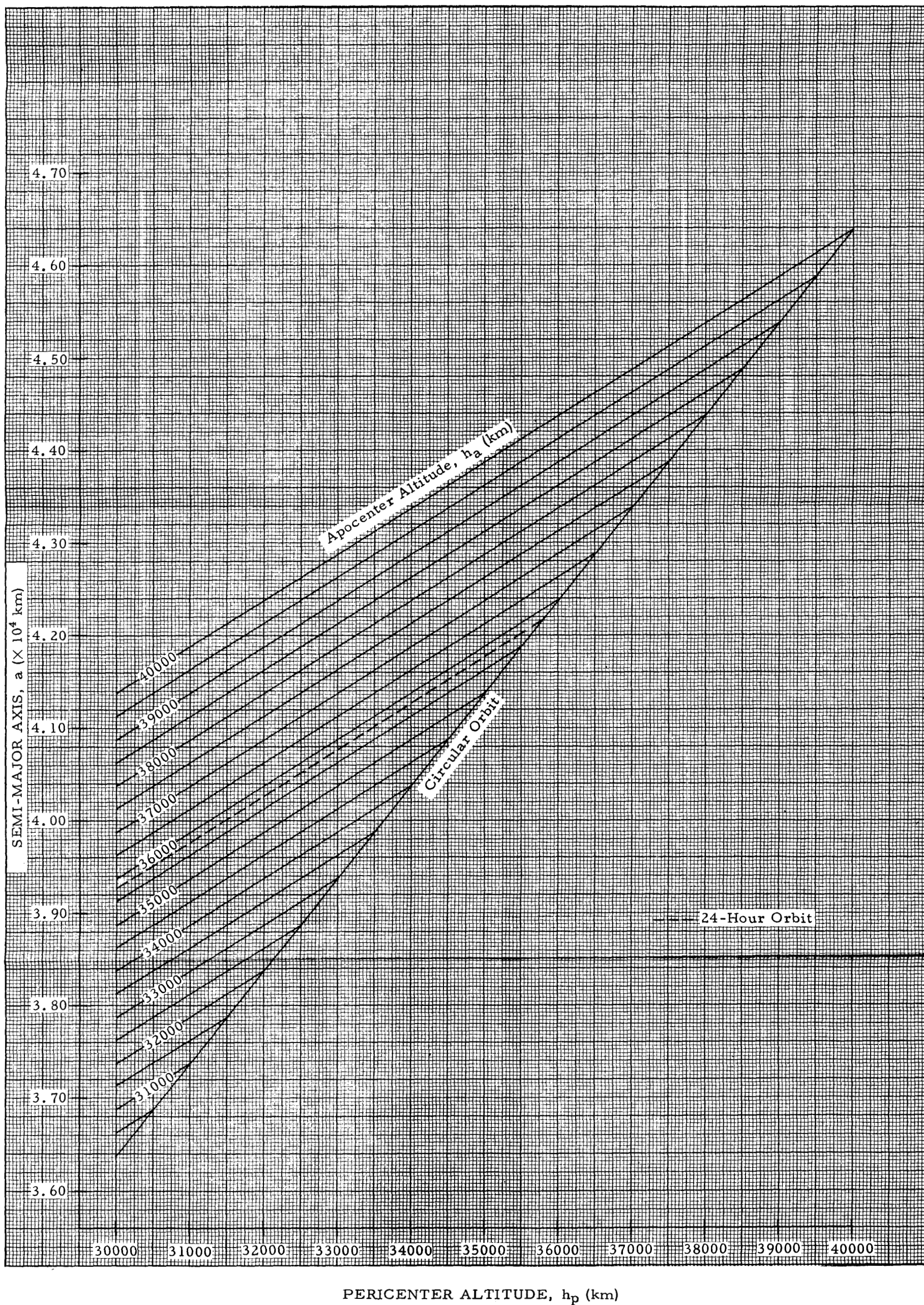


FIGURE 5f. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



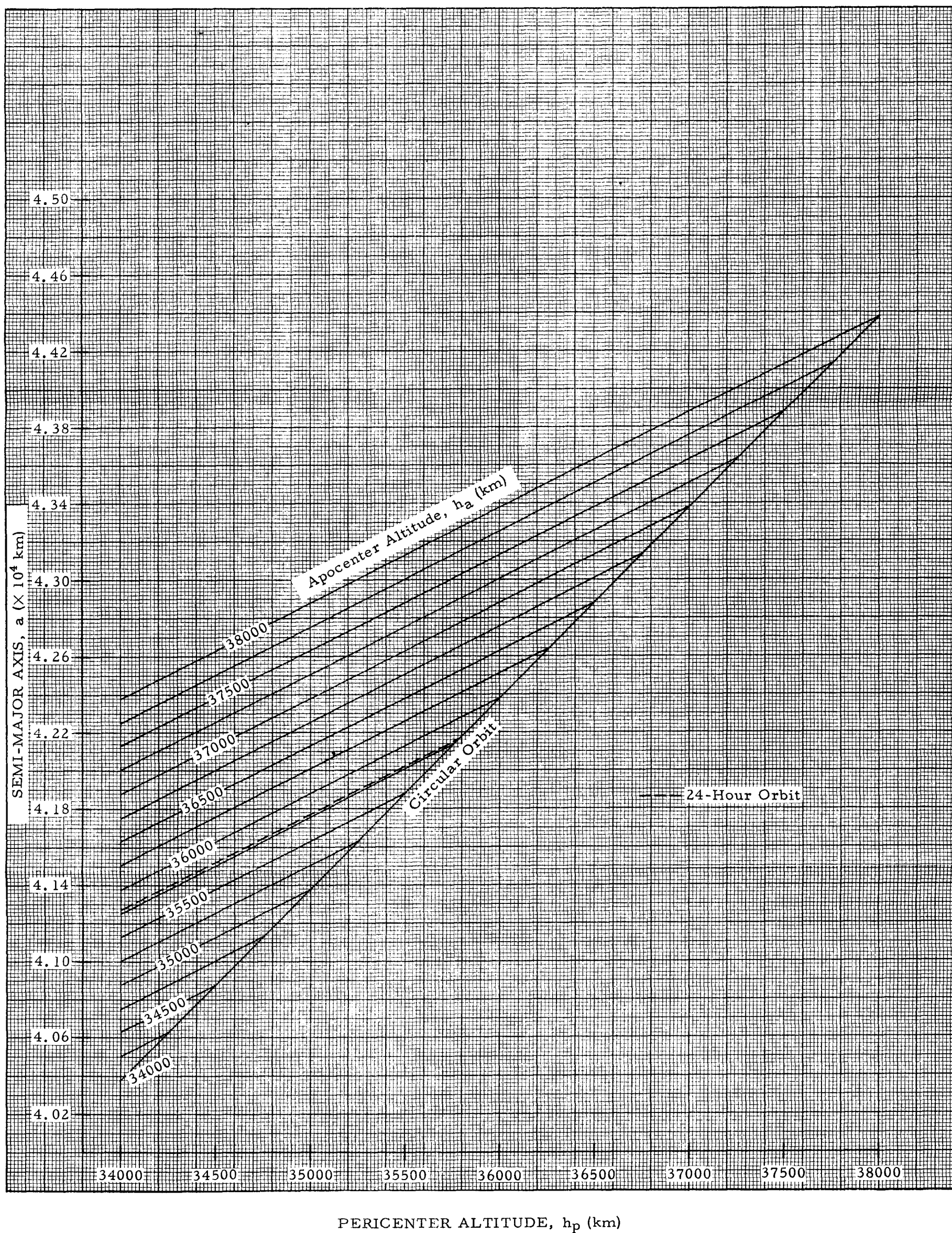


FIGURE 5g. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



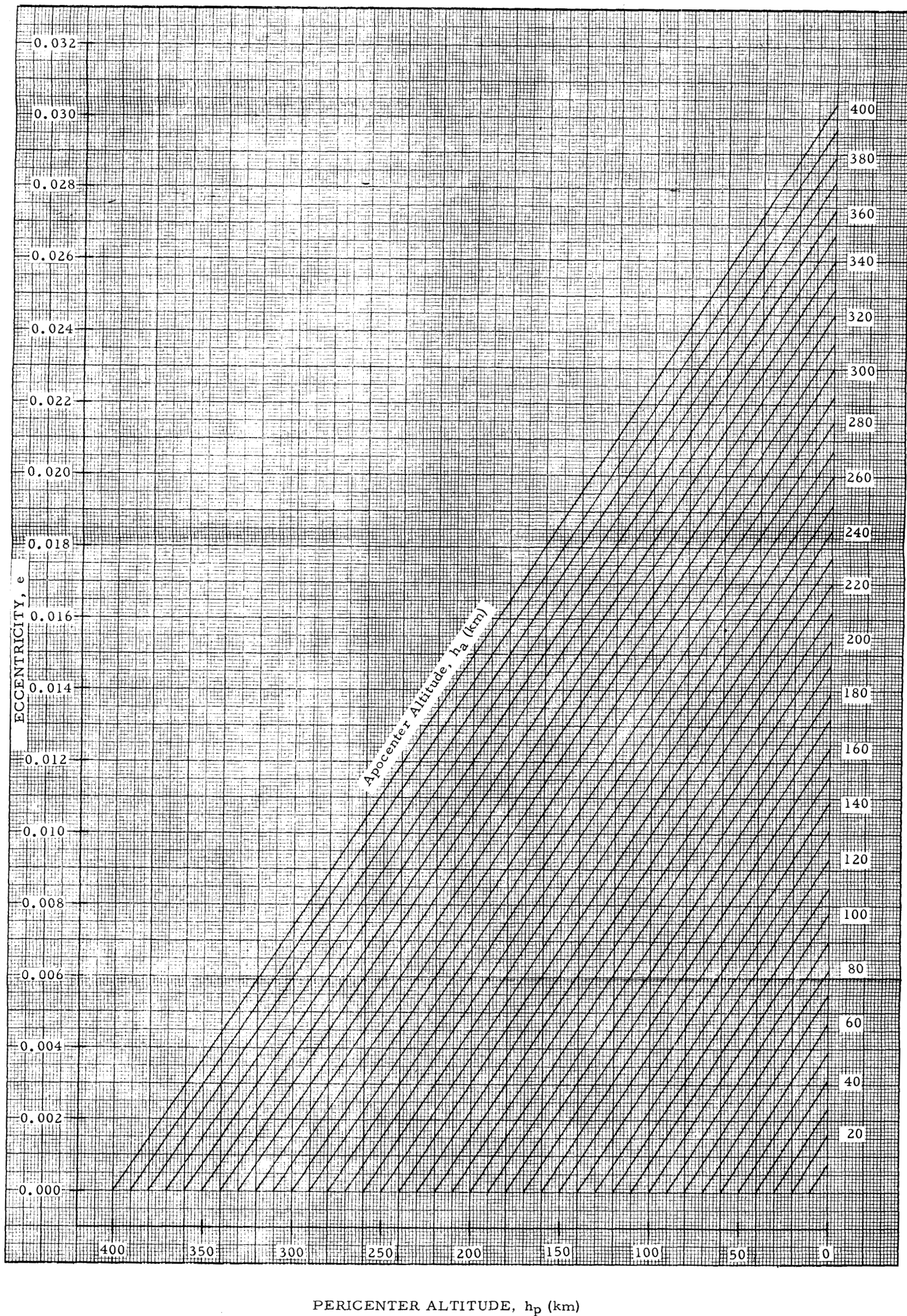


FIGURE 6a. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



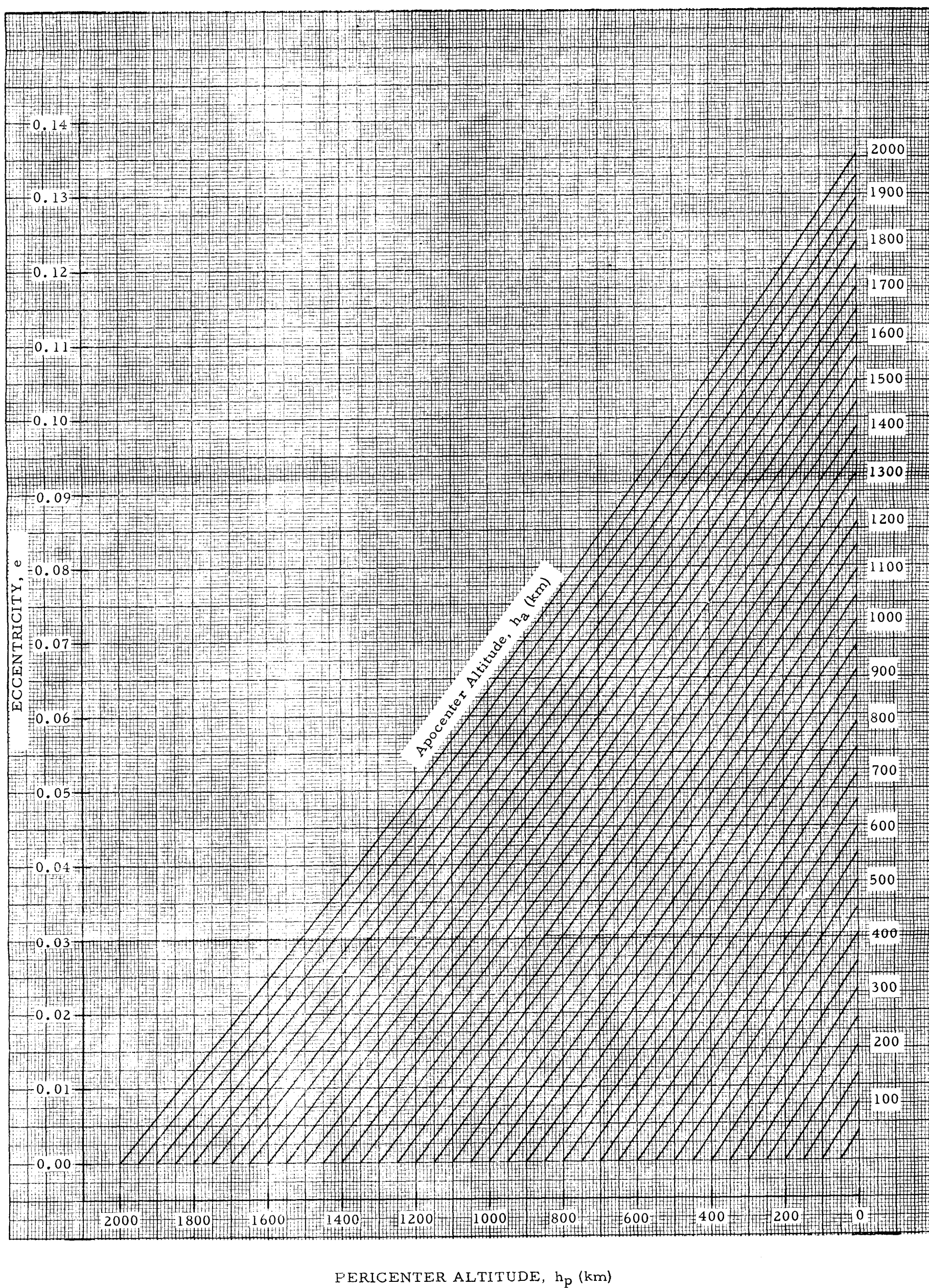


FIGURE 6b. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

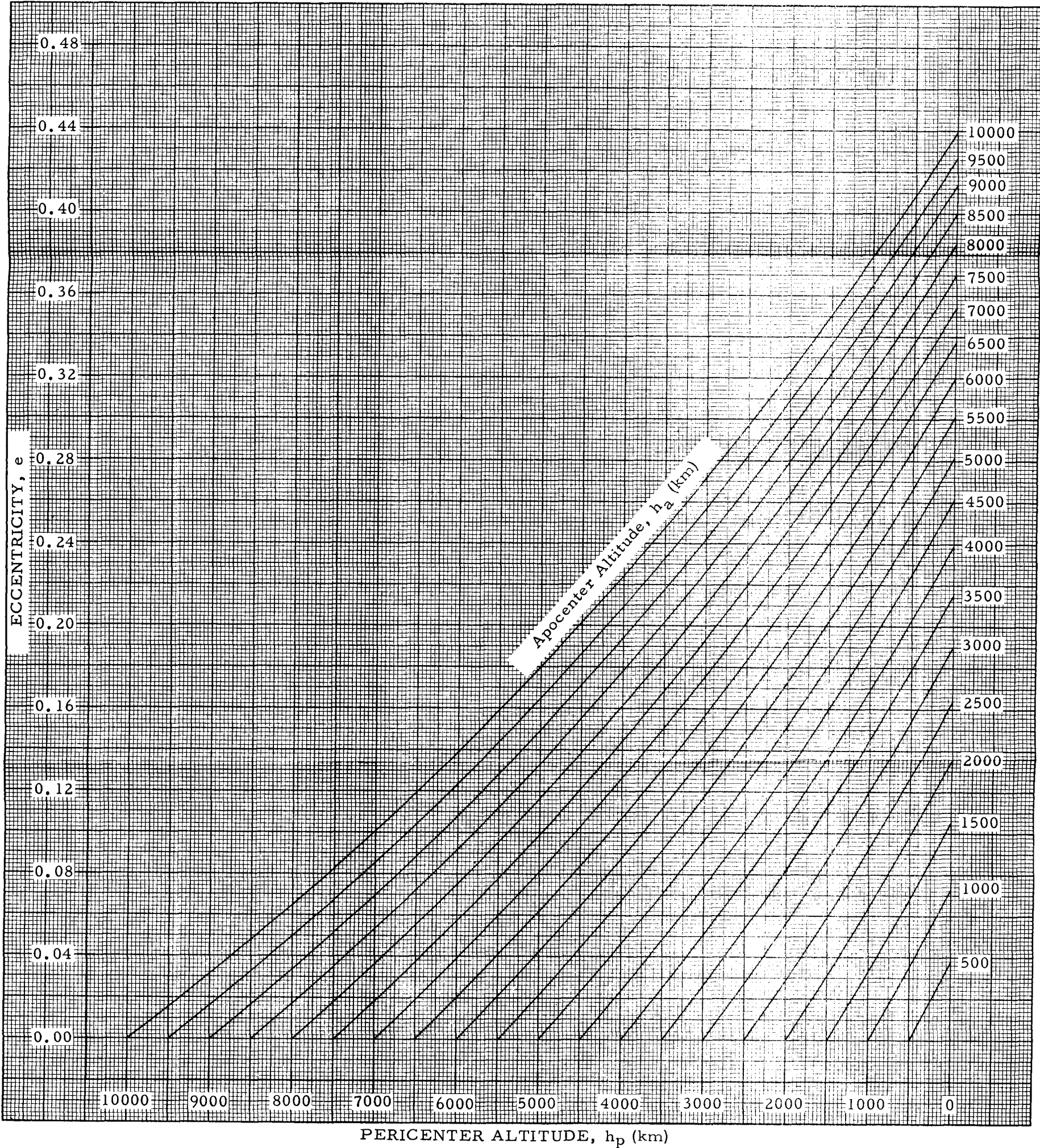


FIGURE 6c. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



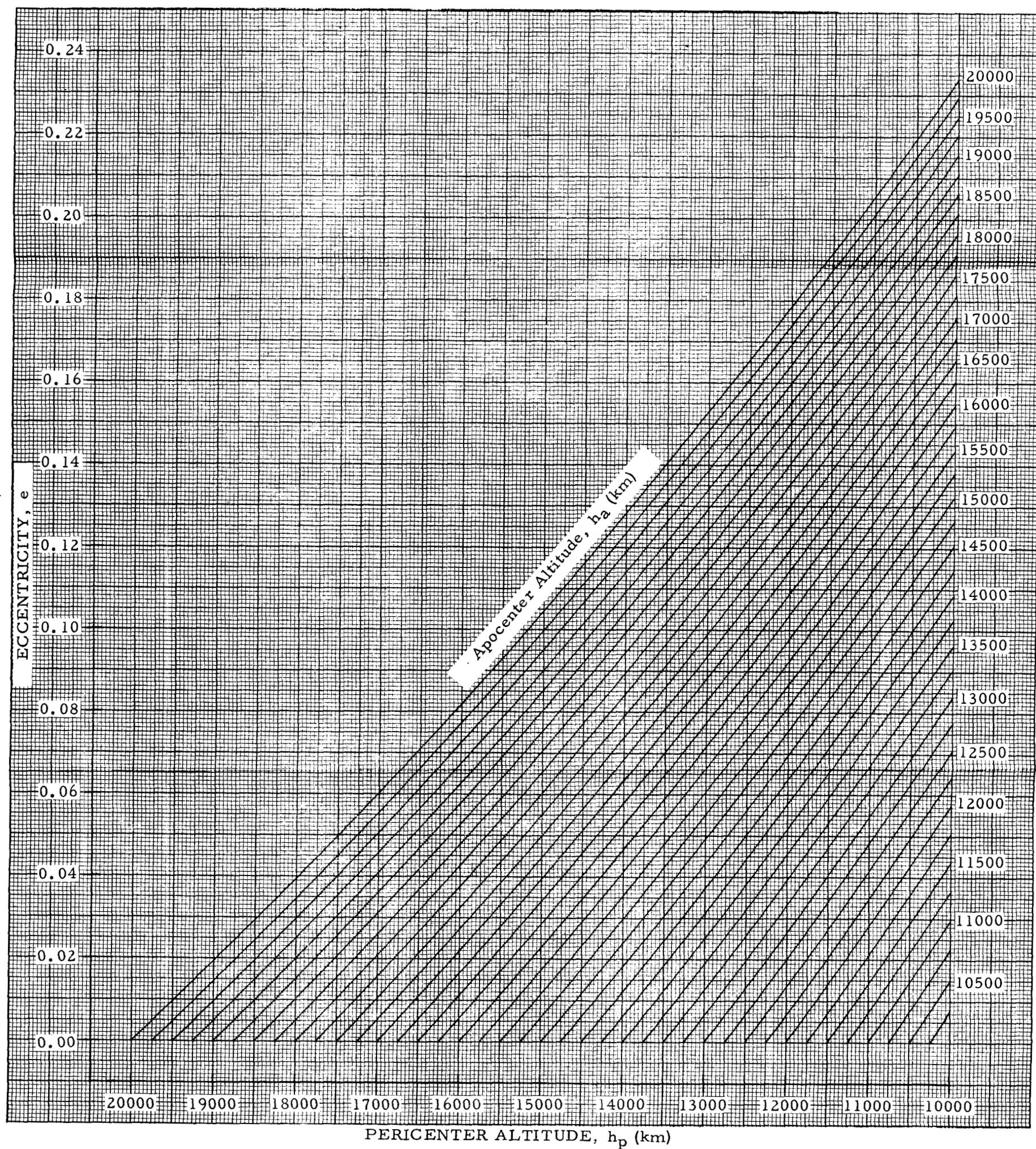


FIGURE 6d. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



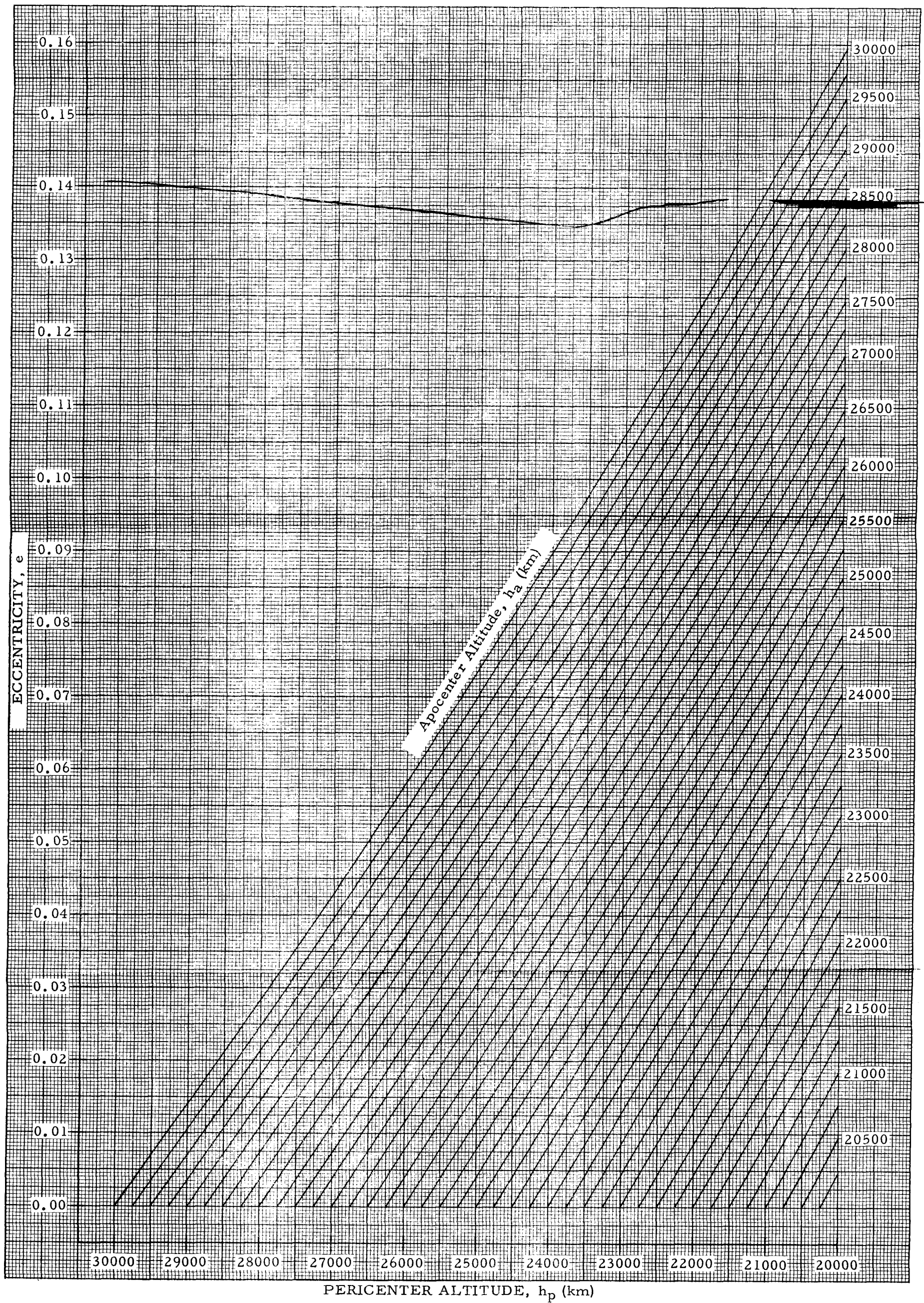


FIGURE 6e. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



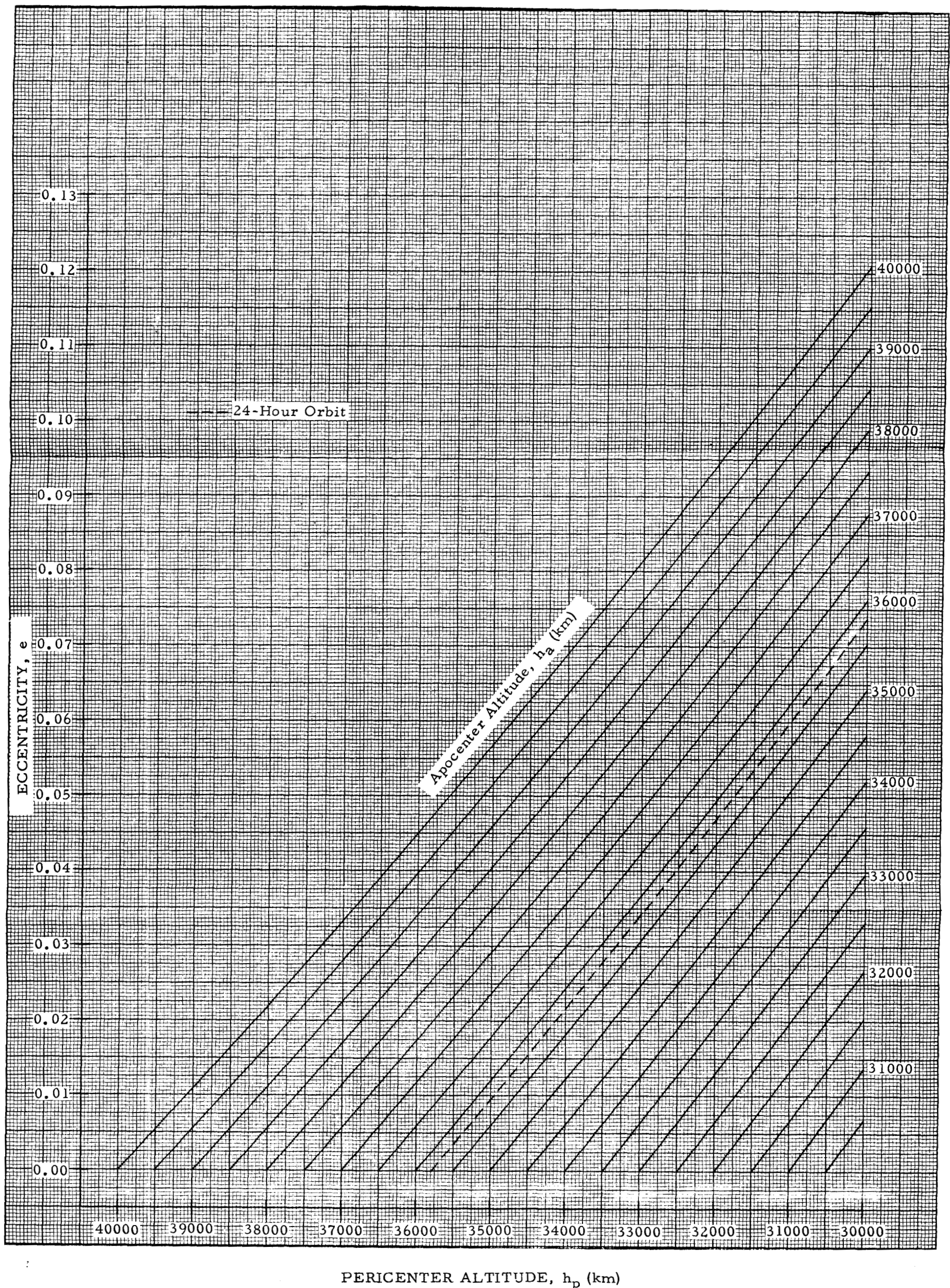


FIGURE 6f. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



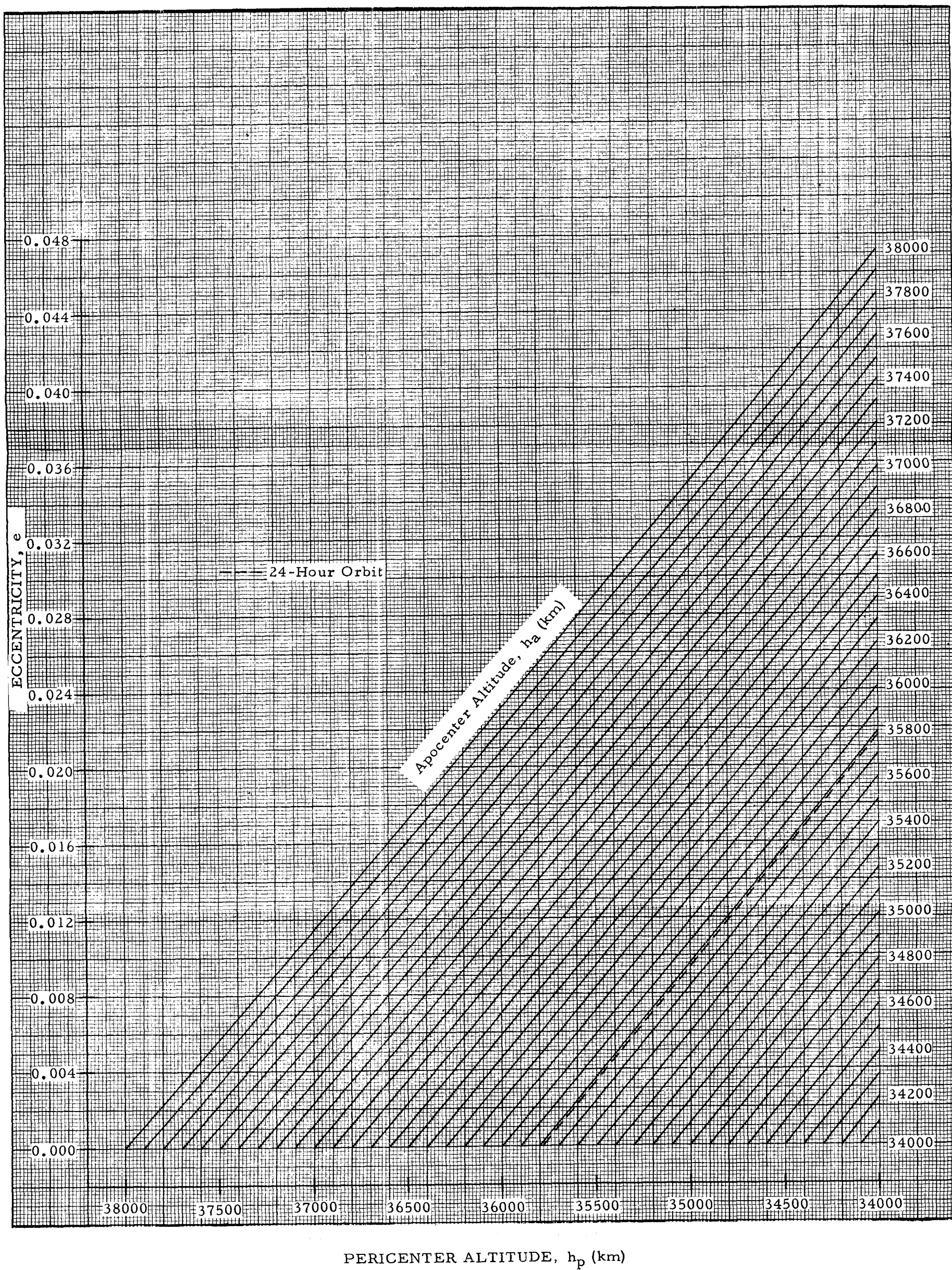


FIGURE 6g. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



ILLUSTRATIONS

SECTION B

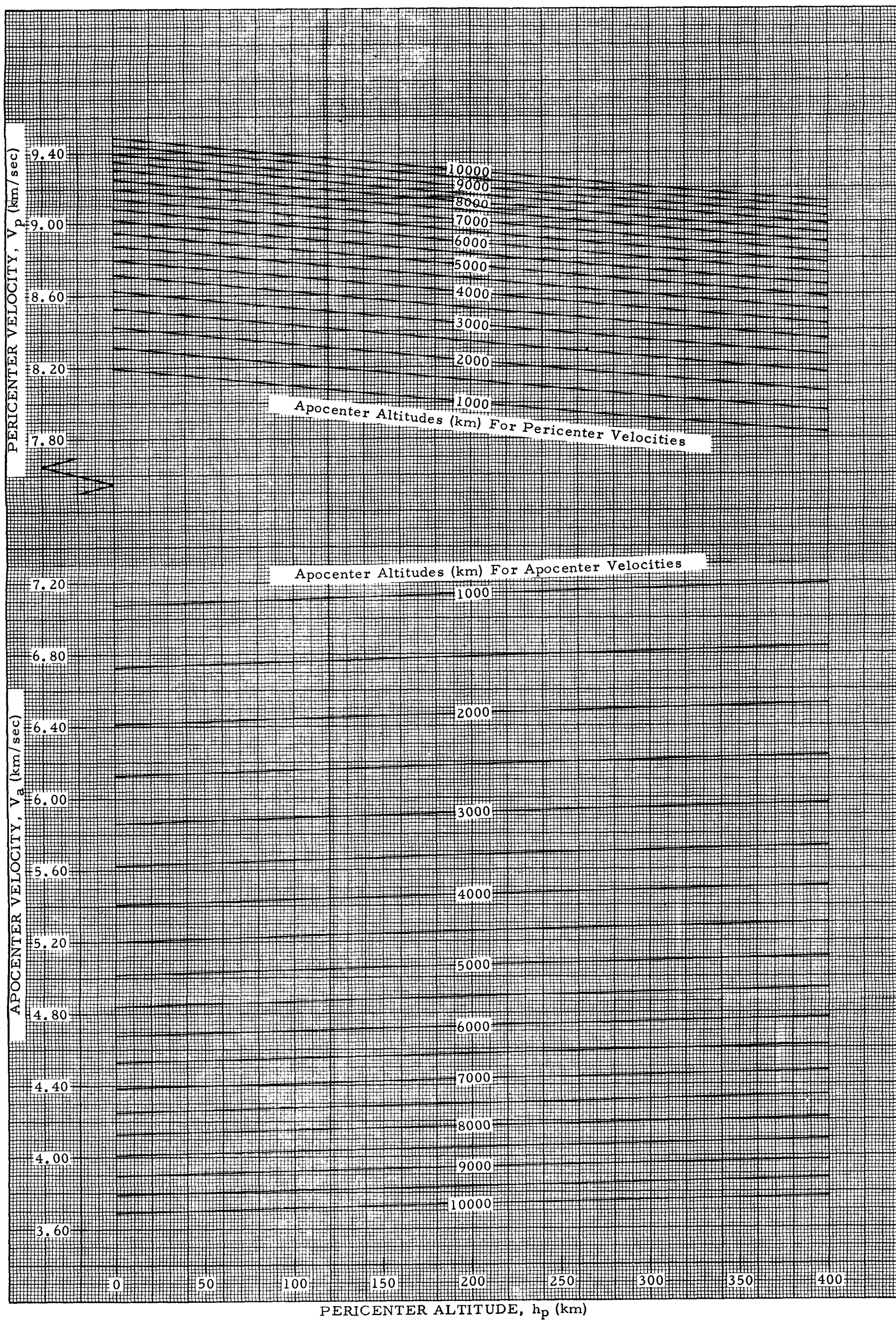


FIGURE 1a. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



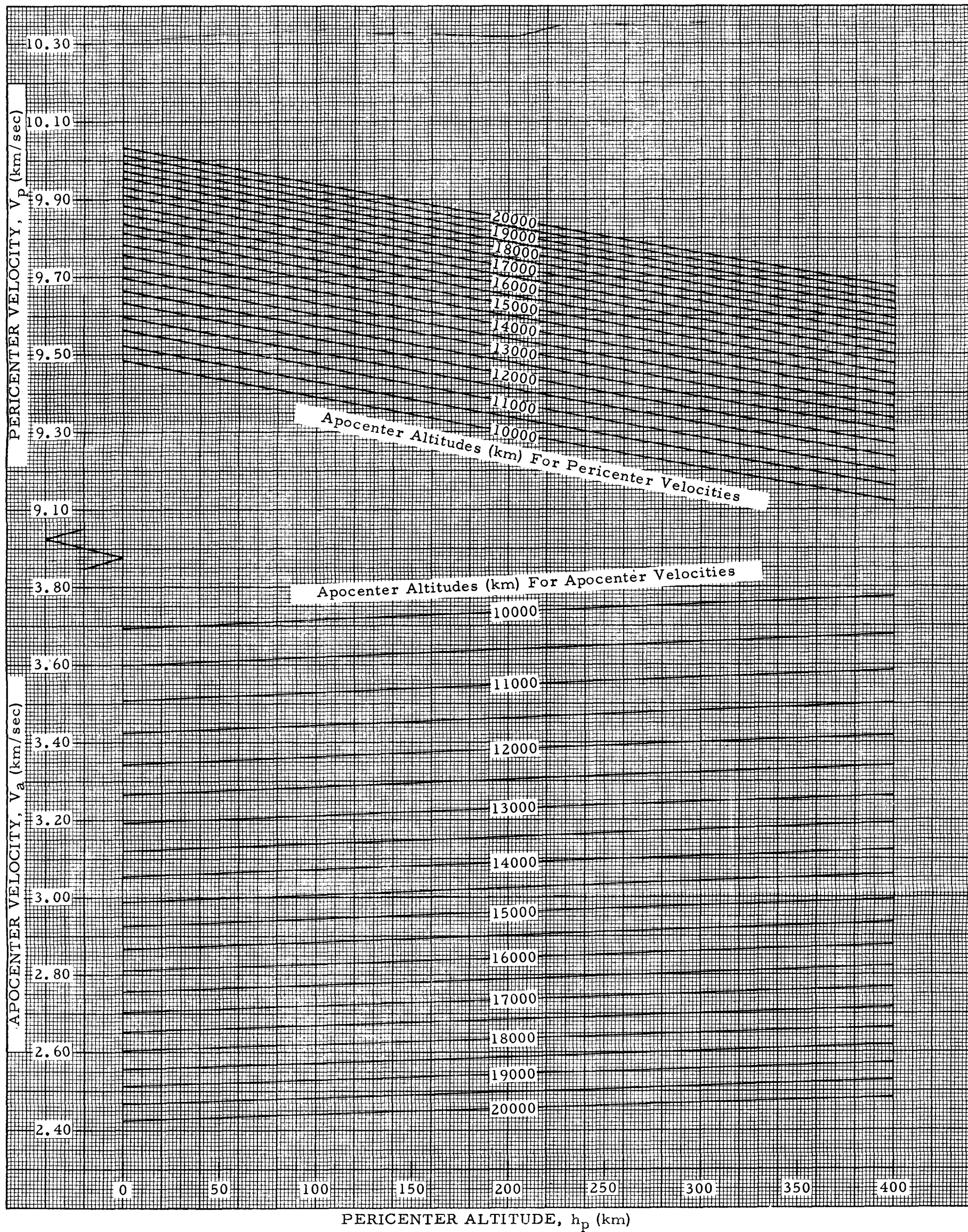


FIGURE 1b. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



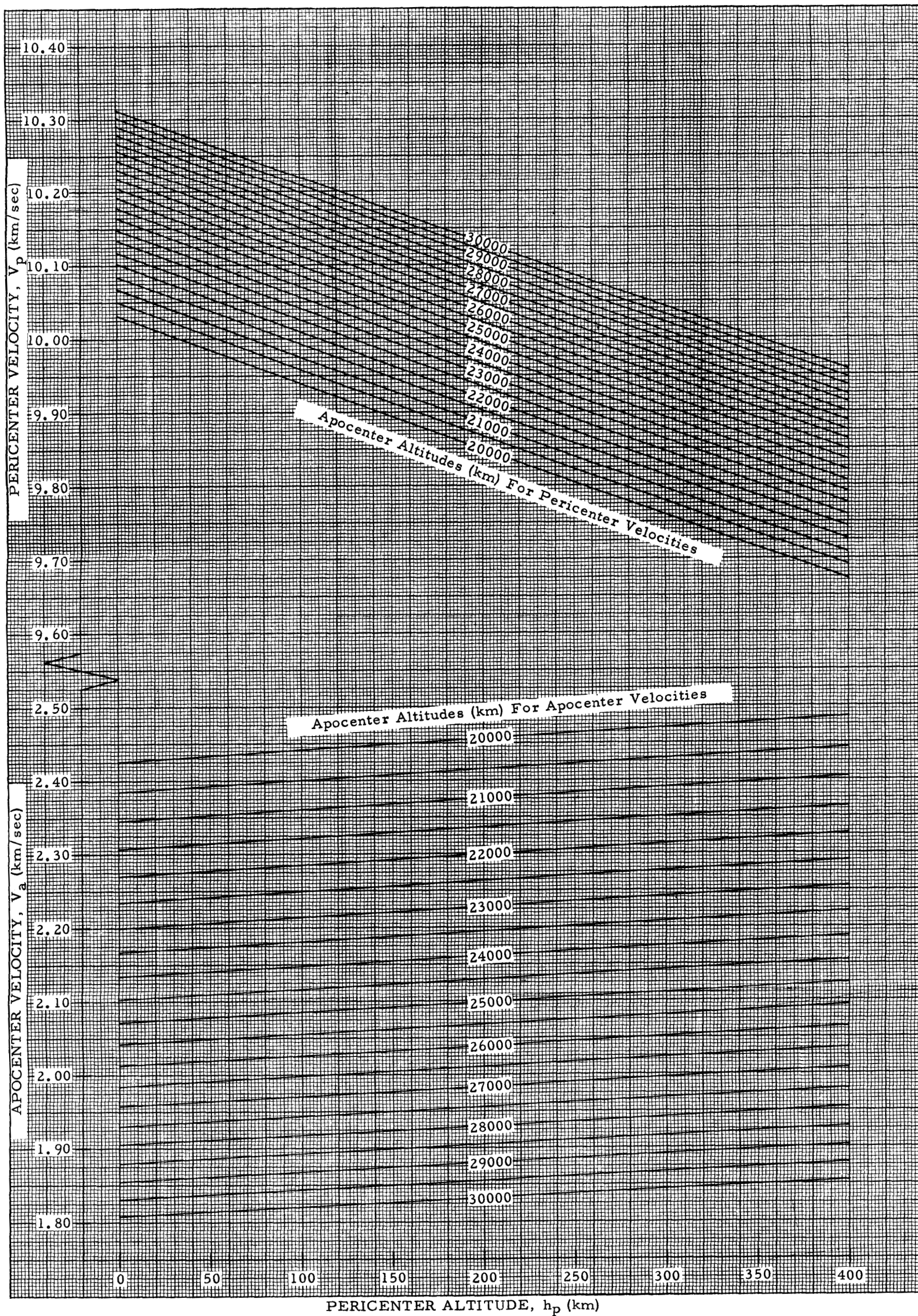


FIGURE 1c. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



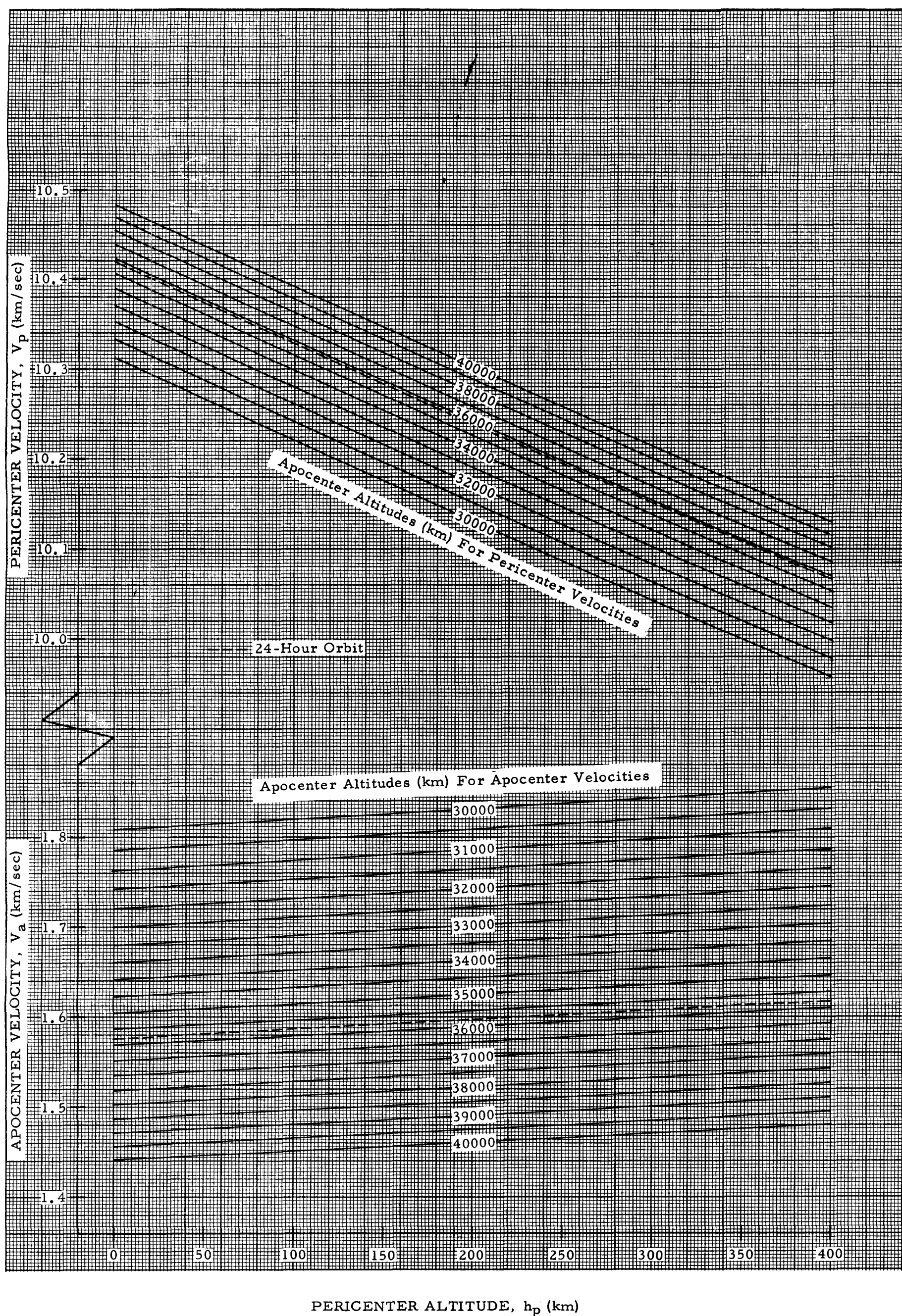


FIGURE 1d. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



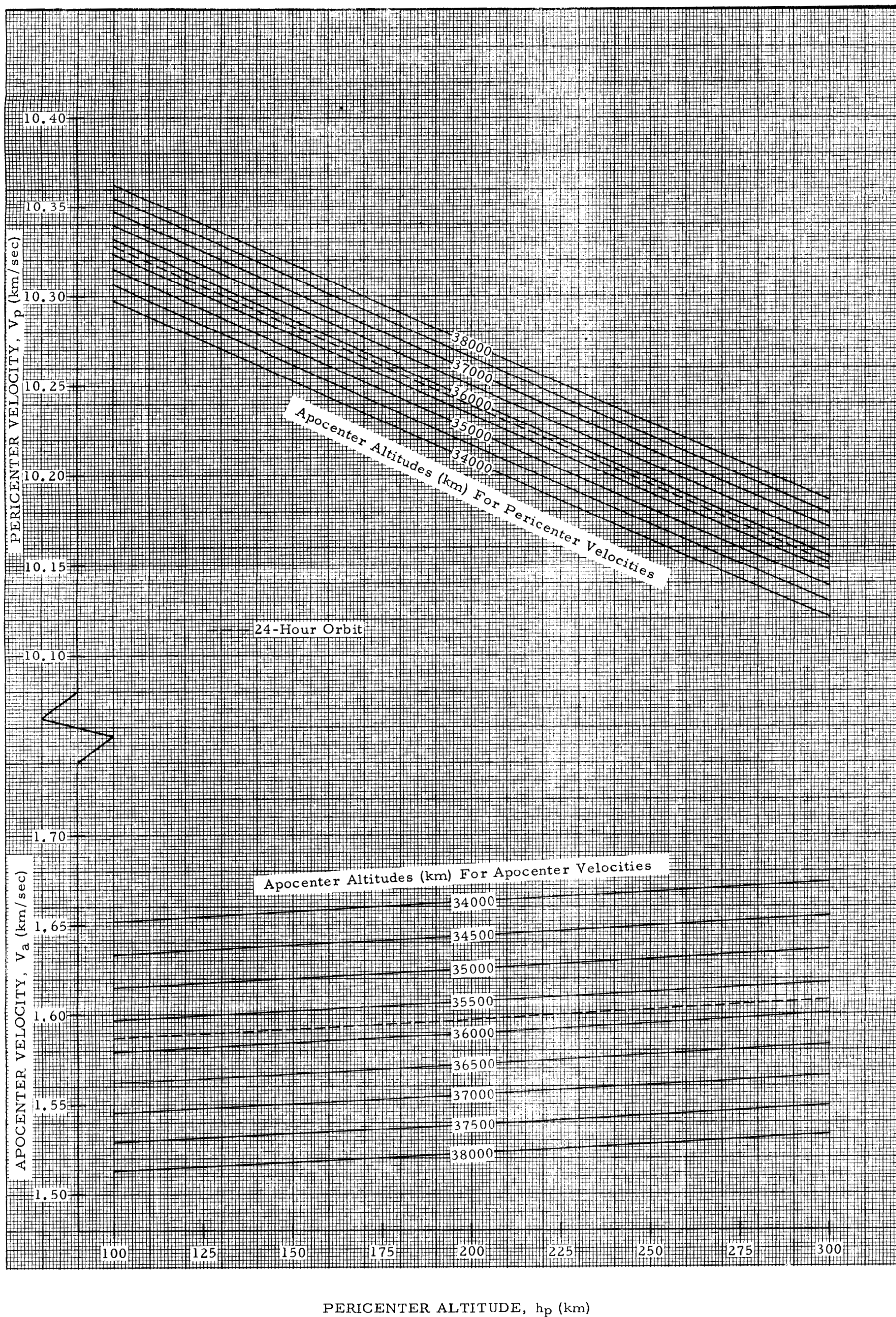


FIGURE 1e. VELOCITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE FOR PERICENTER VELOCITIES AND APOCENTER ALTITUDE FOR APOCENTER VELOCITIES AS PARAMETERS



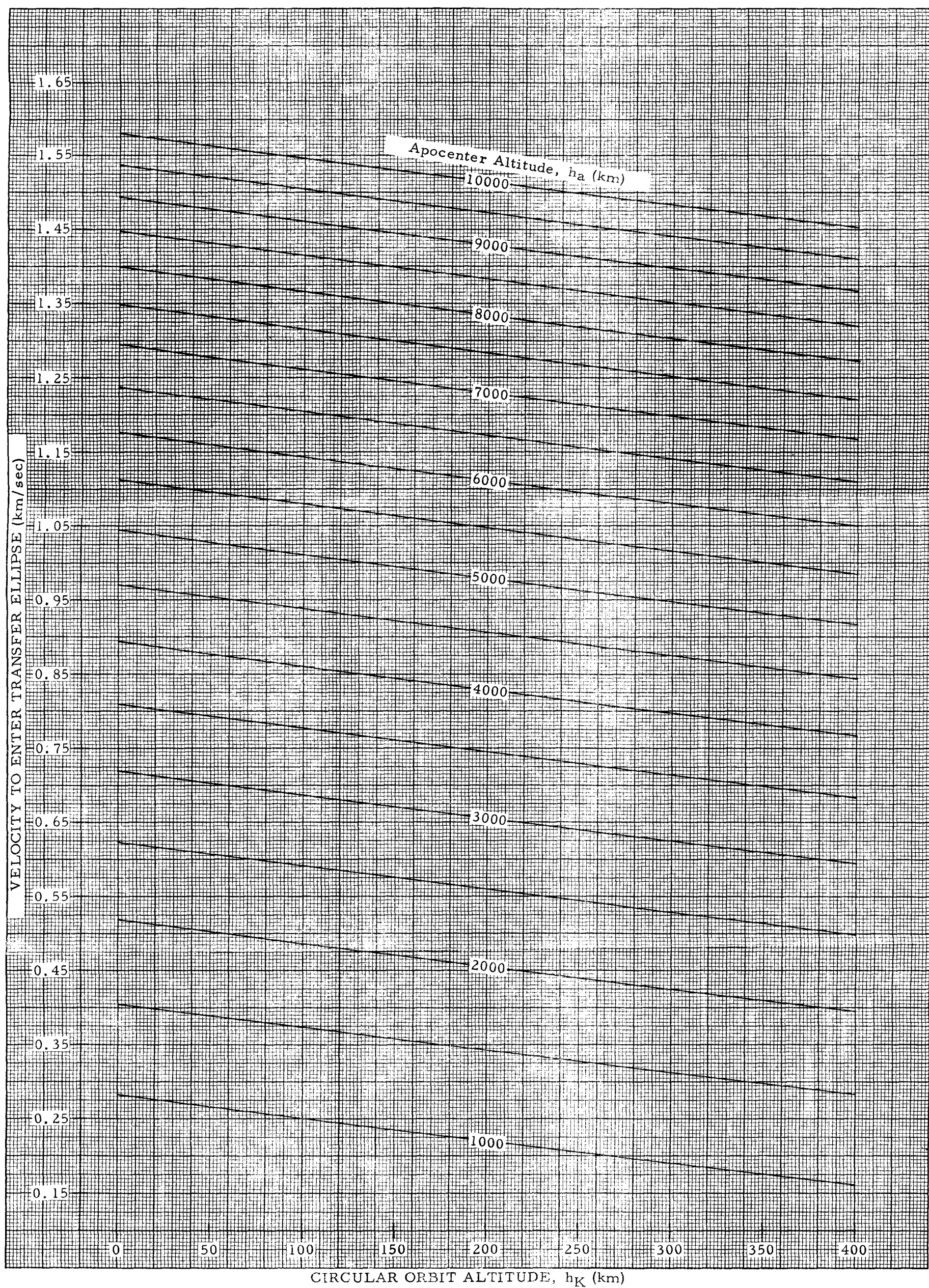


FIGURE 2a. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



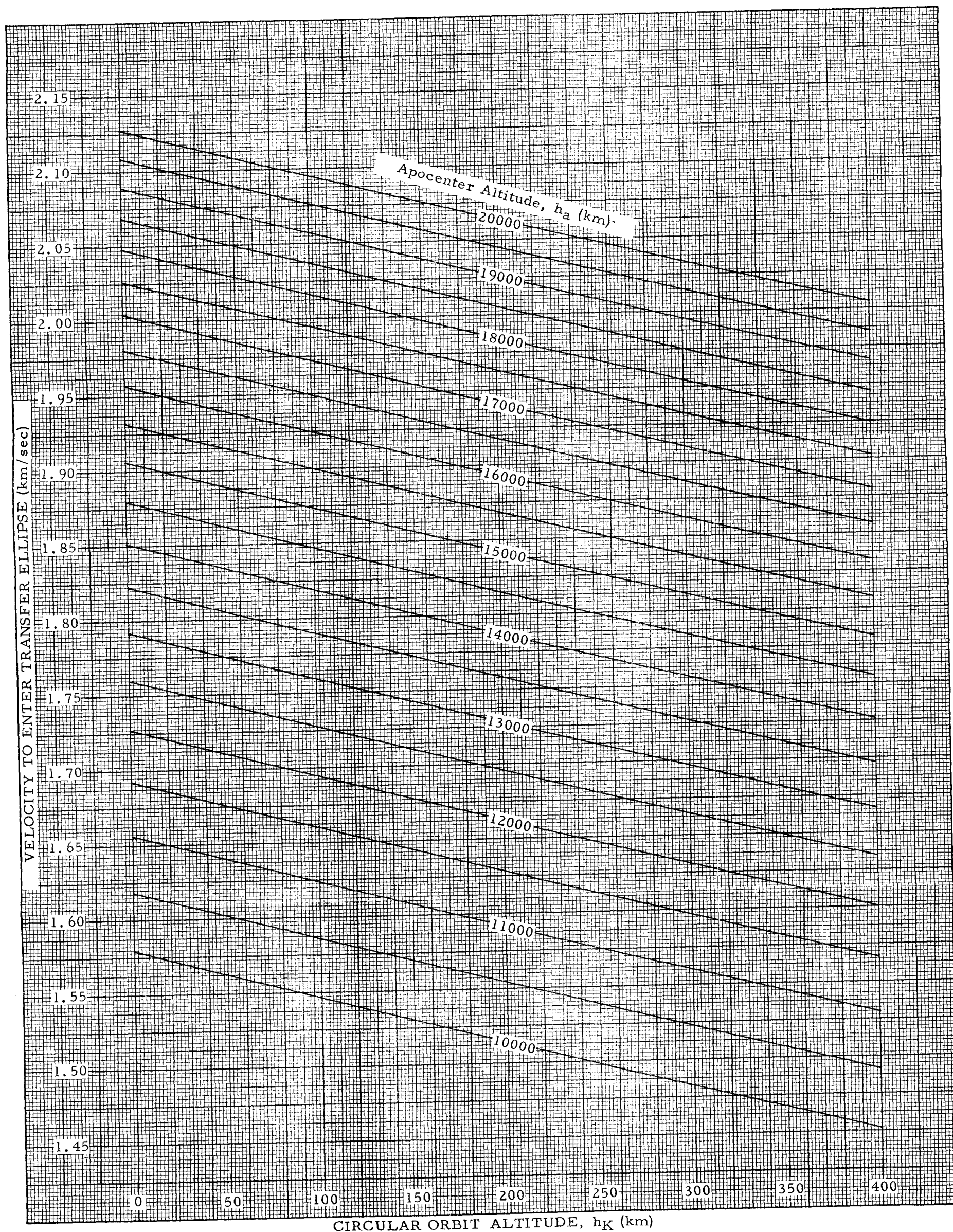


FIGURE 2b. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



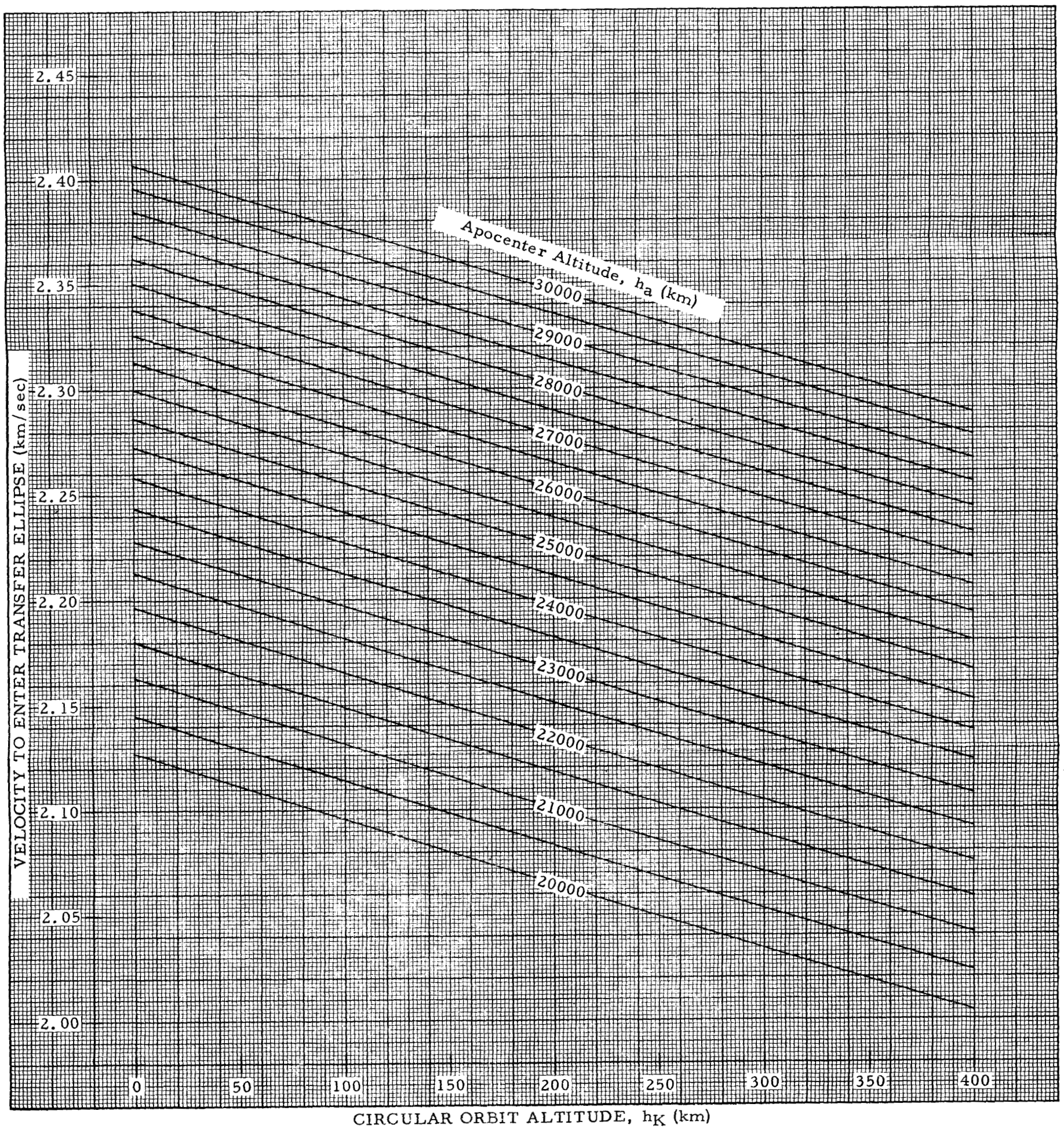


FIGURE 2c. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



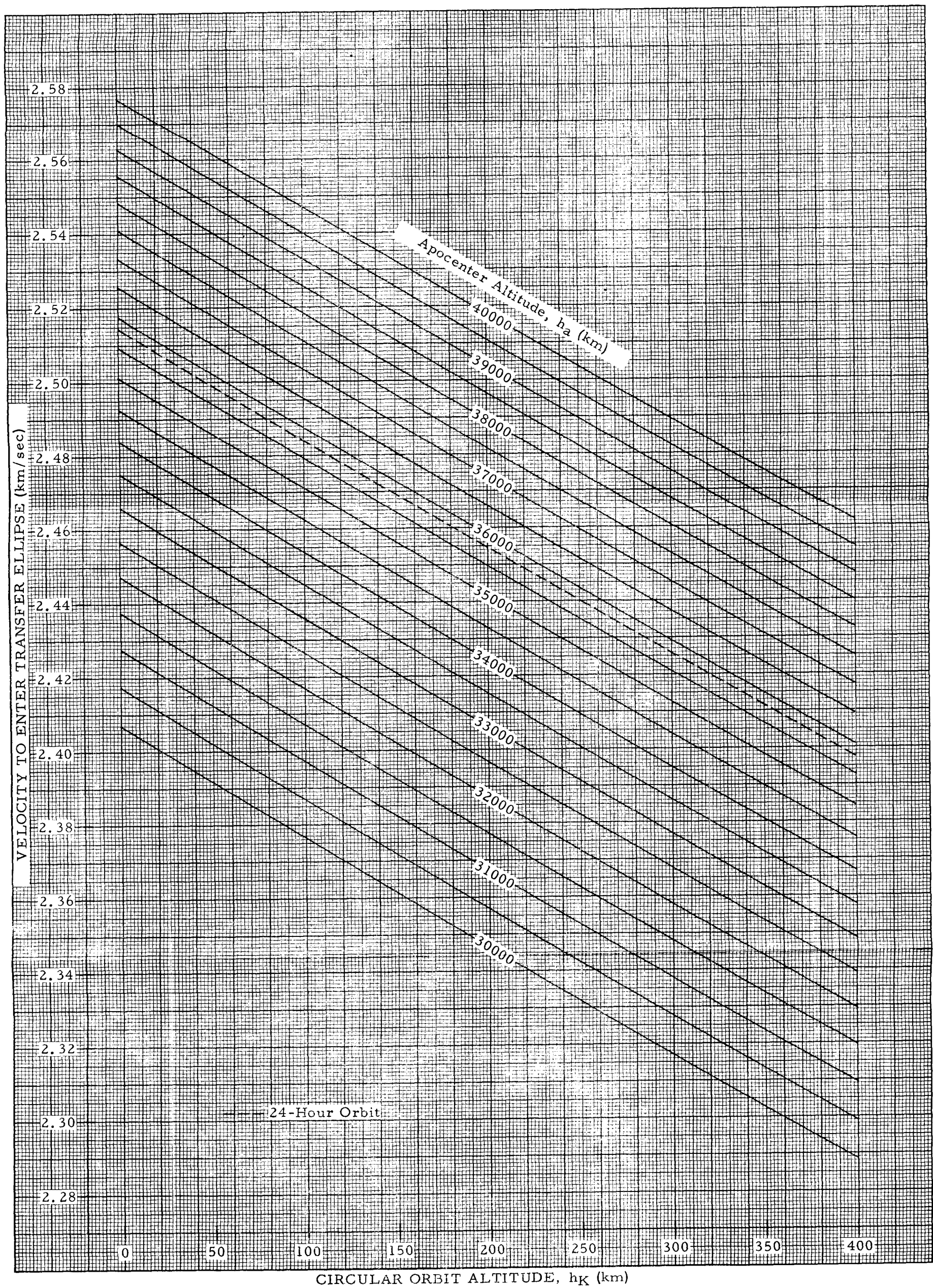


FIGURE 2d. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



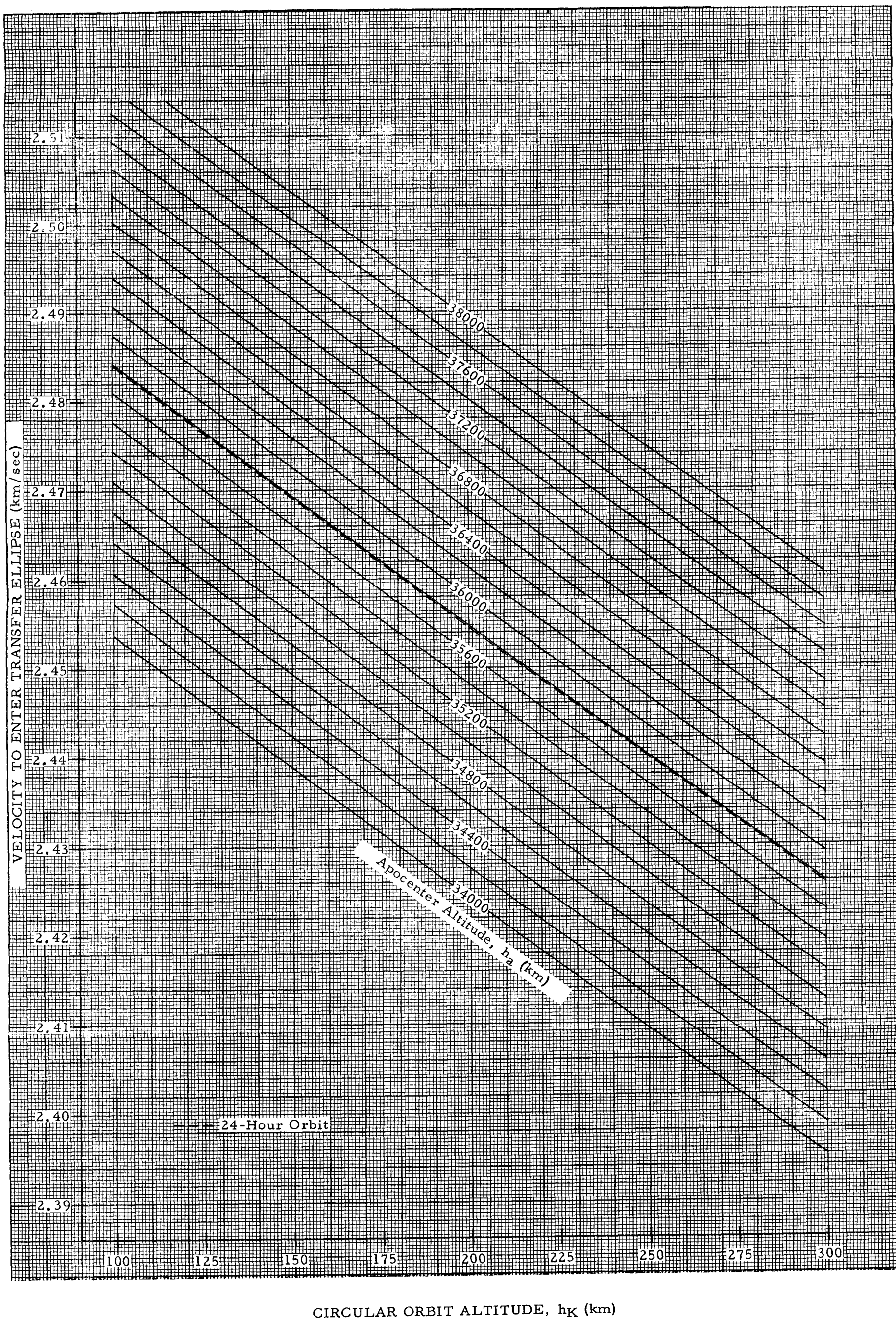


FIGURE 2e. VELOCITY REQUIRED FOR TRANSFER FROM A CIRCULAR TO AN ECCENTRIC ORBIT VERSUS CIRCULAR ORBIT ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



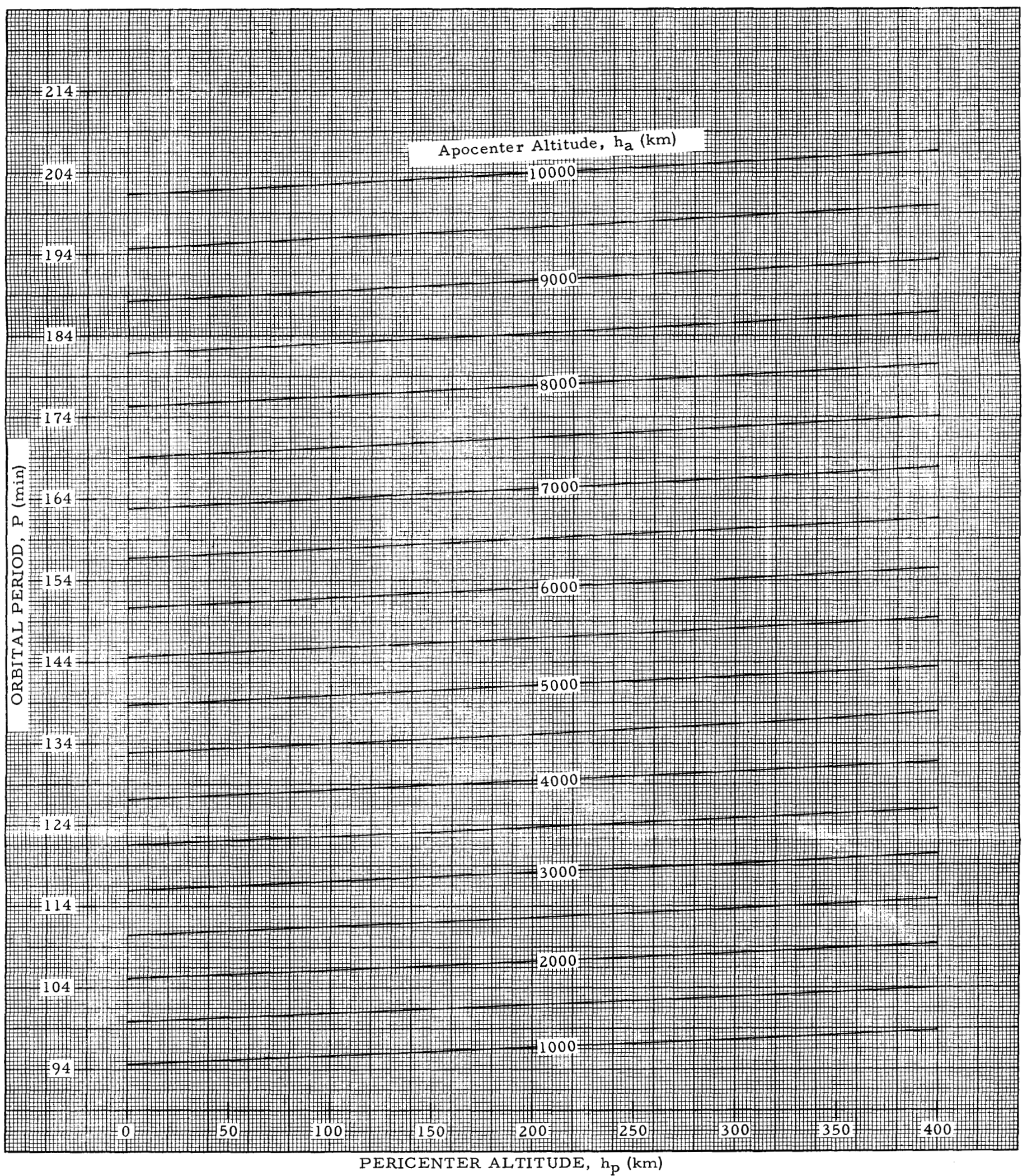


FIGURE 3a. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



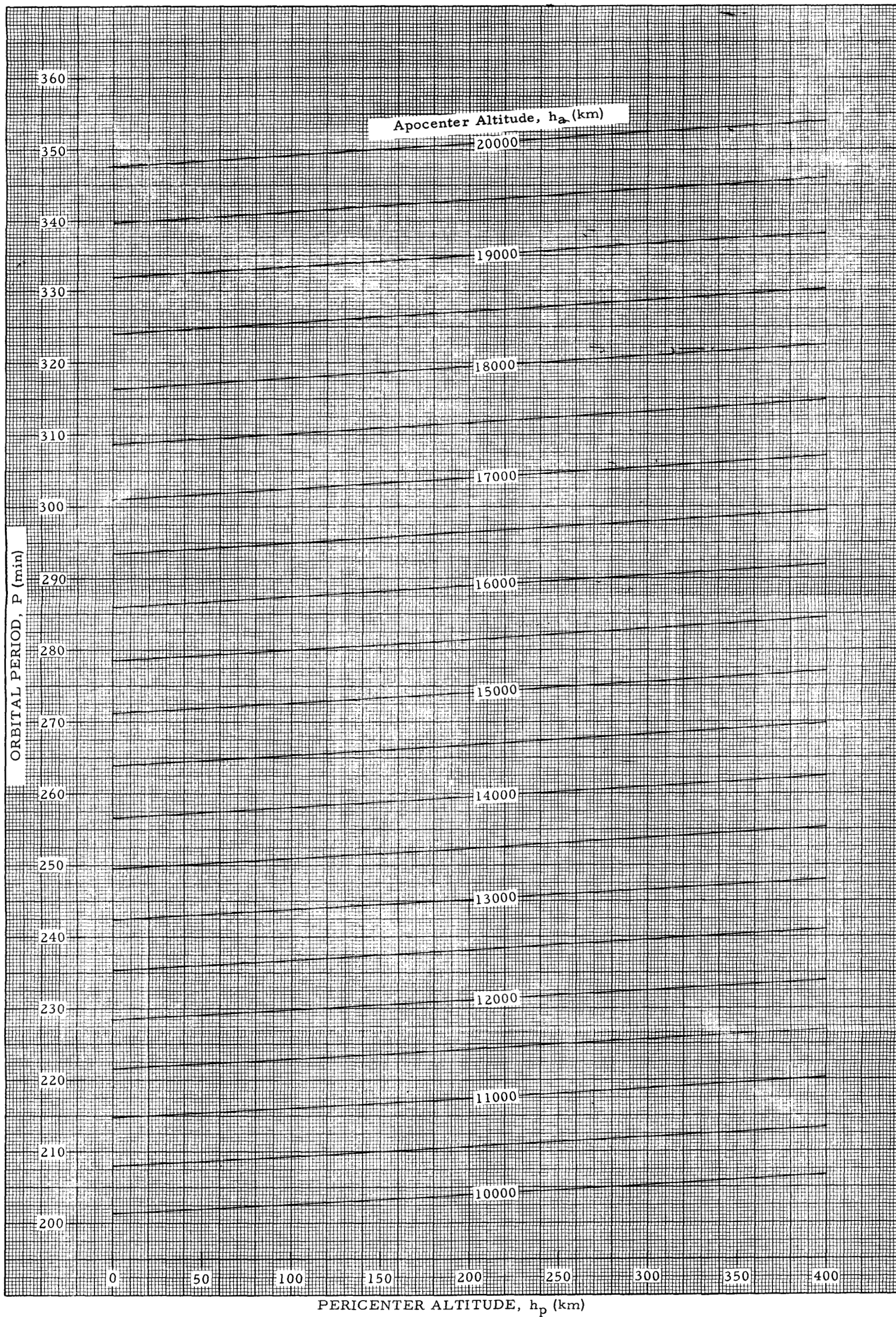


FIGURE 3b. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



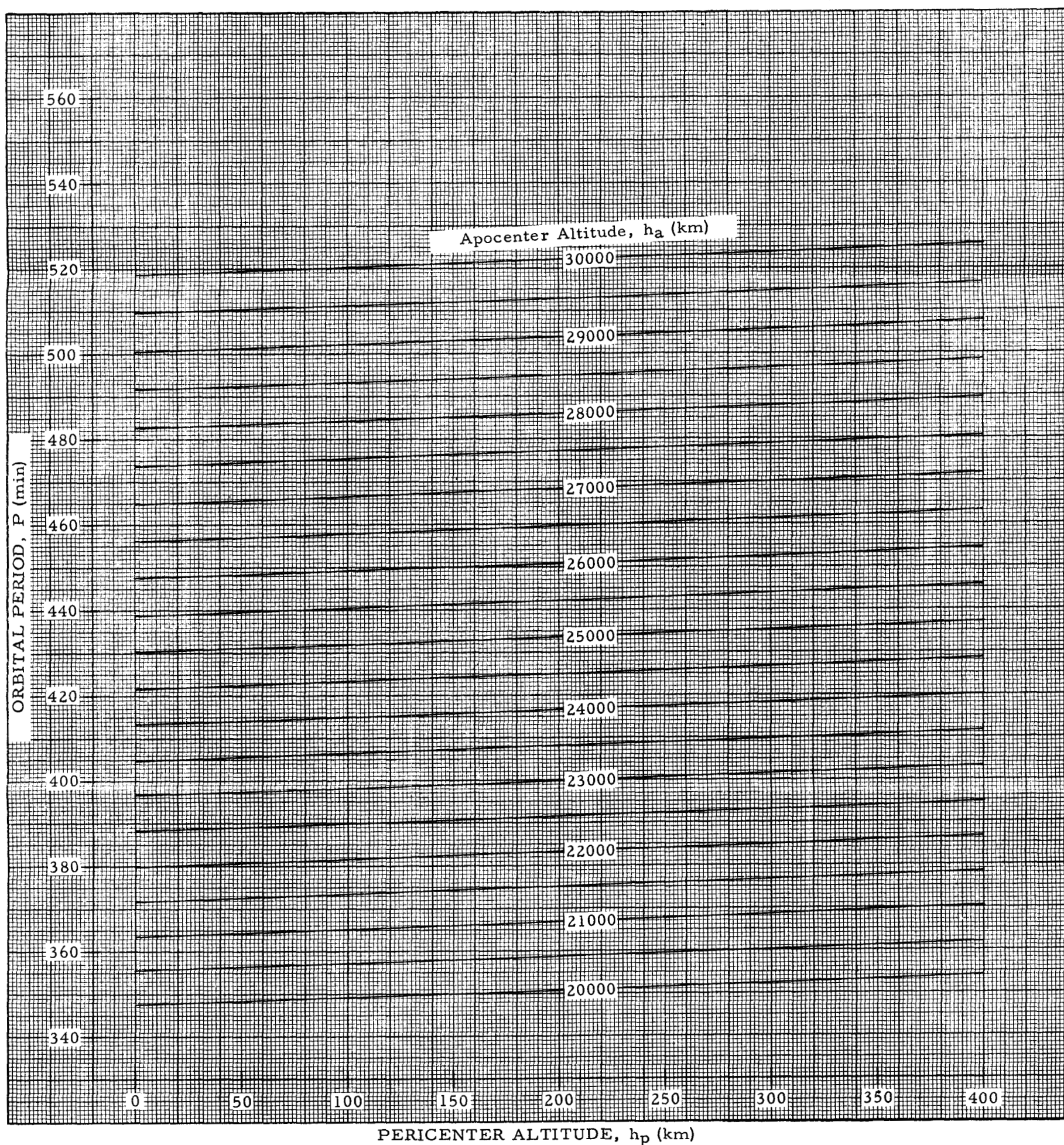


FIGURE 3c. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



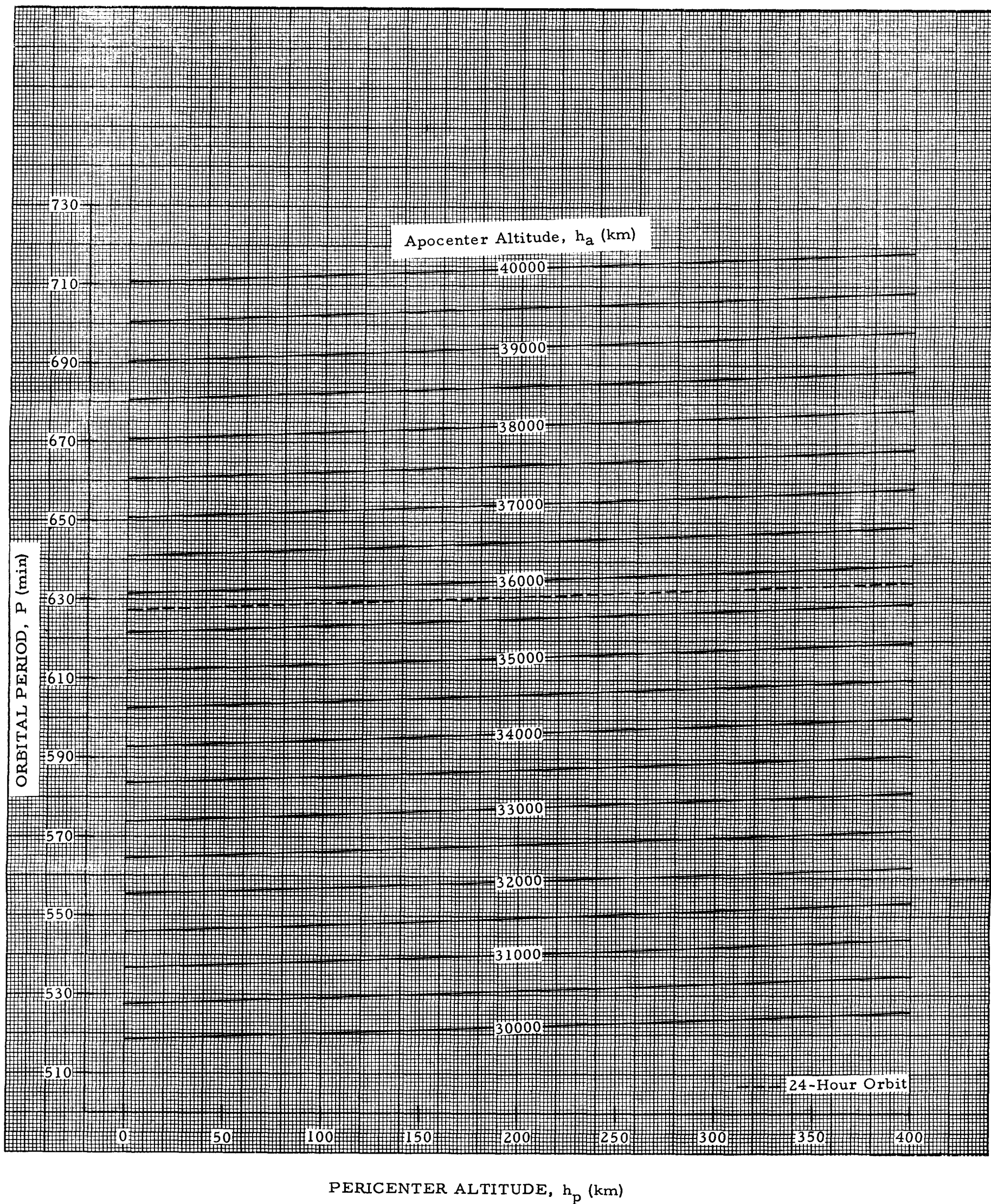


FIGURE 3d. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

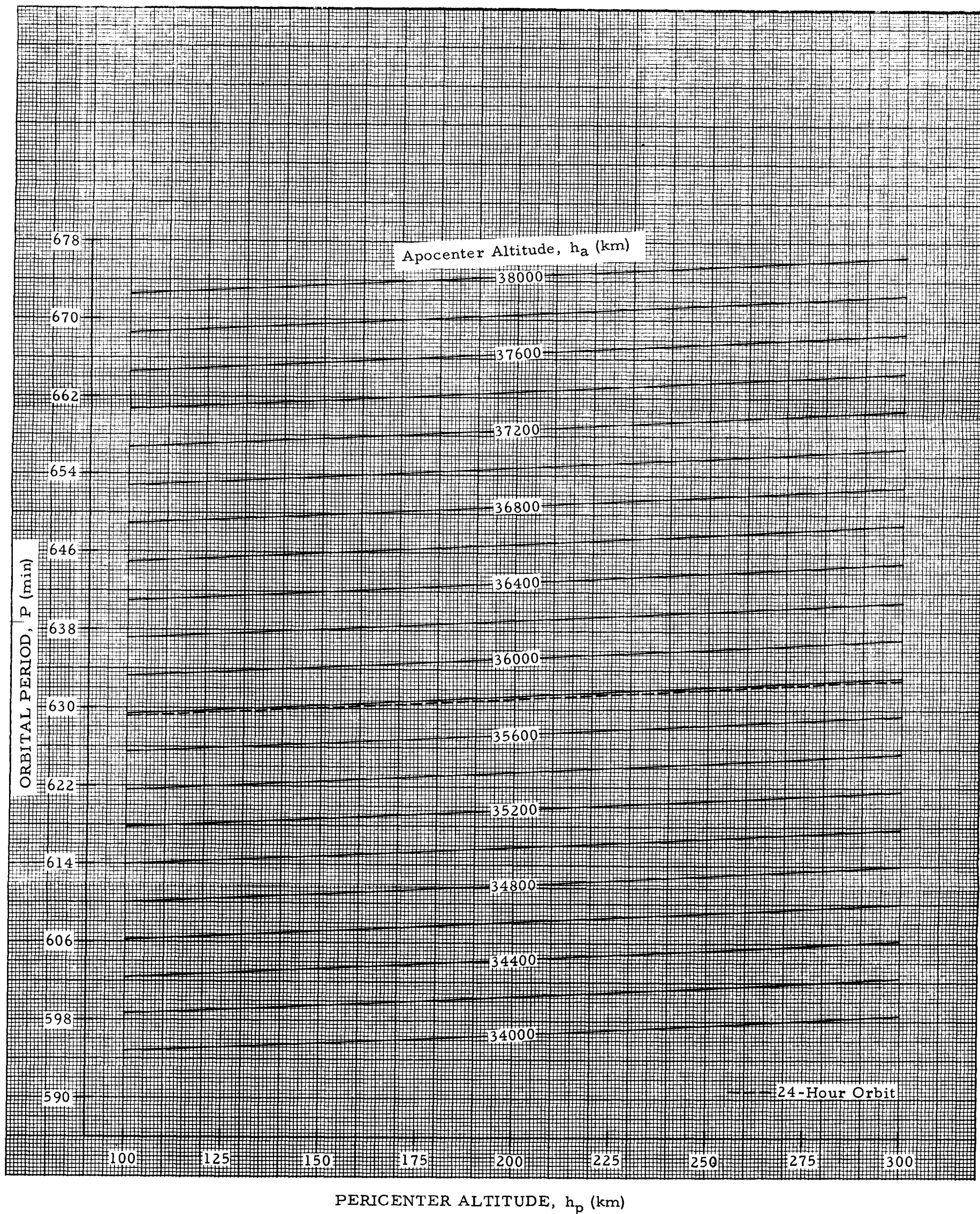


FIGURE 3e. ORBITAL PERIOD VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



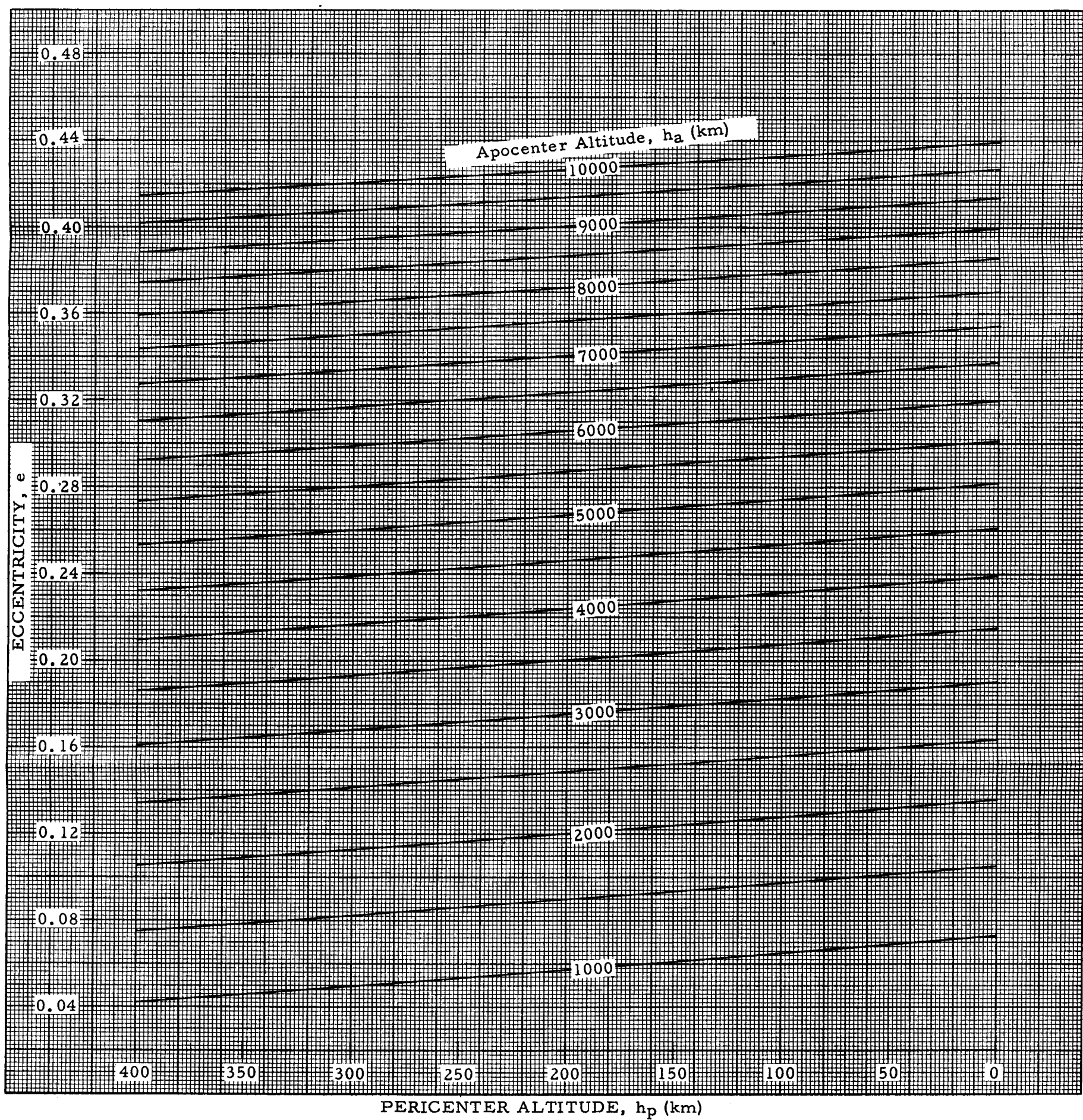


FIGURE 4a. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

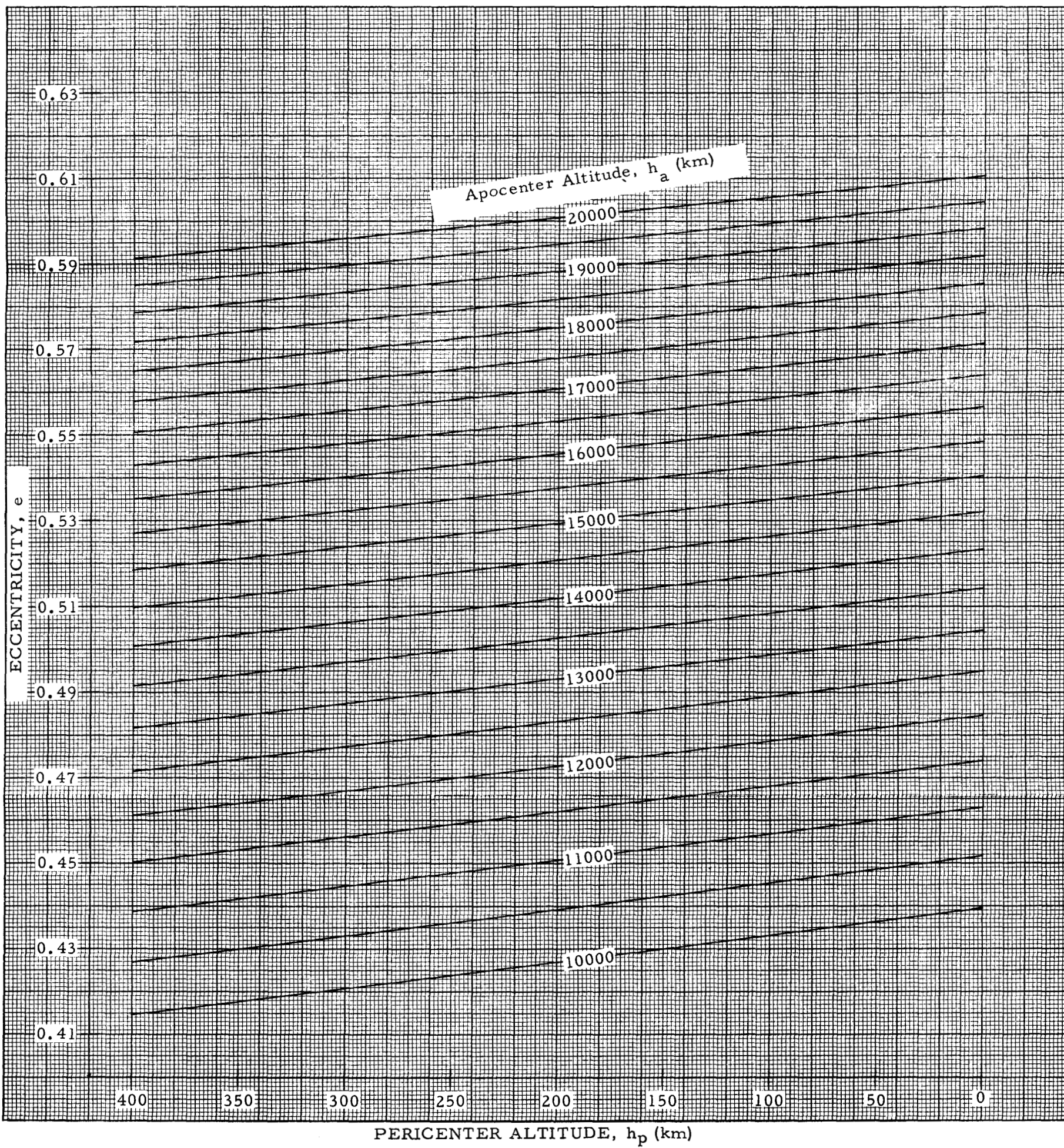


FIGURE 4b. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



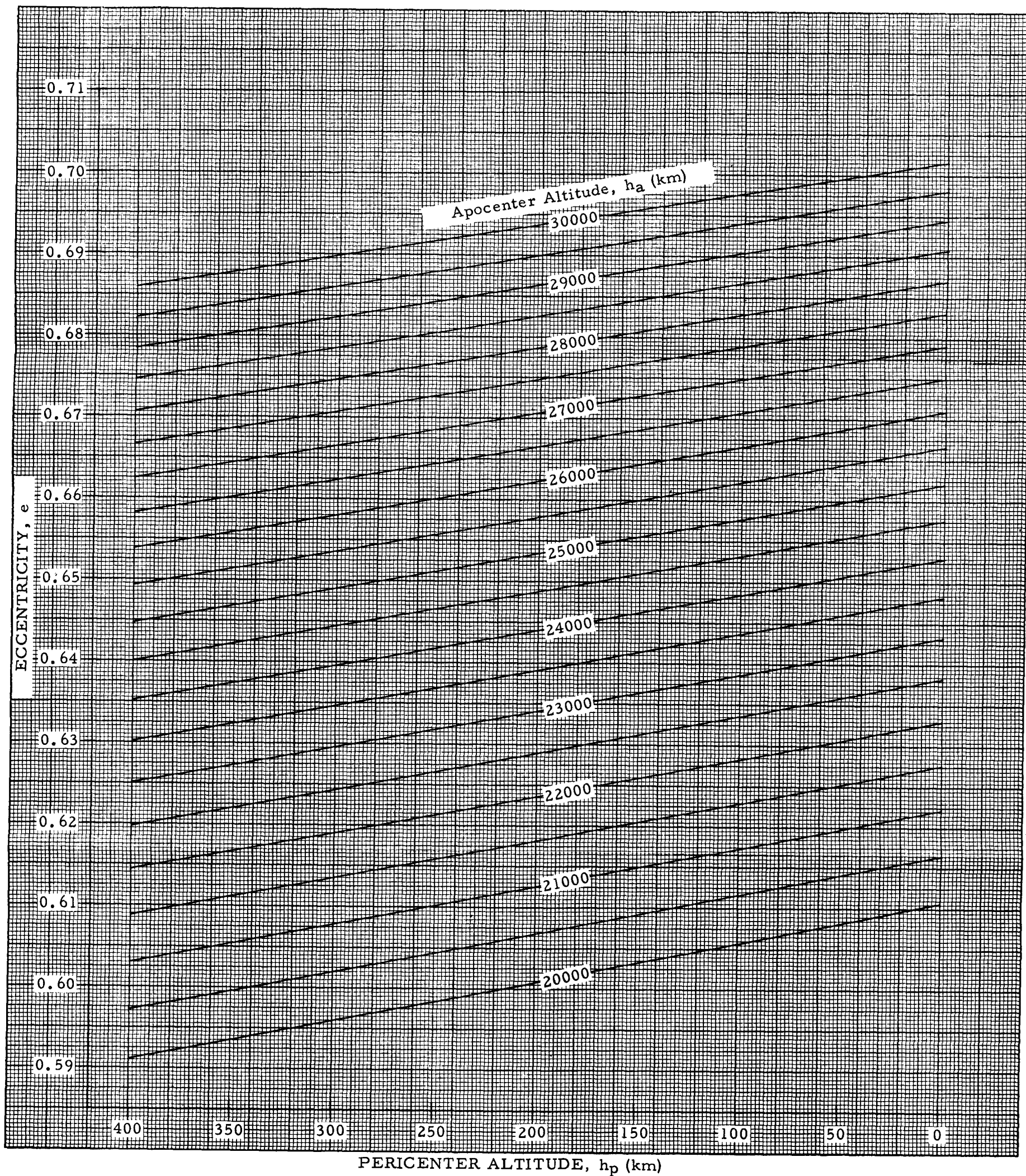


FIGURE 4c. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



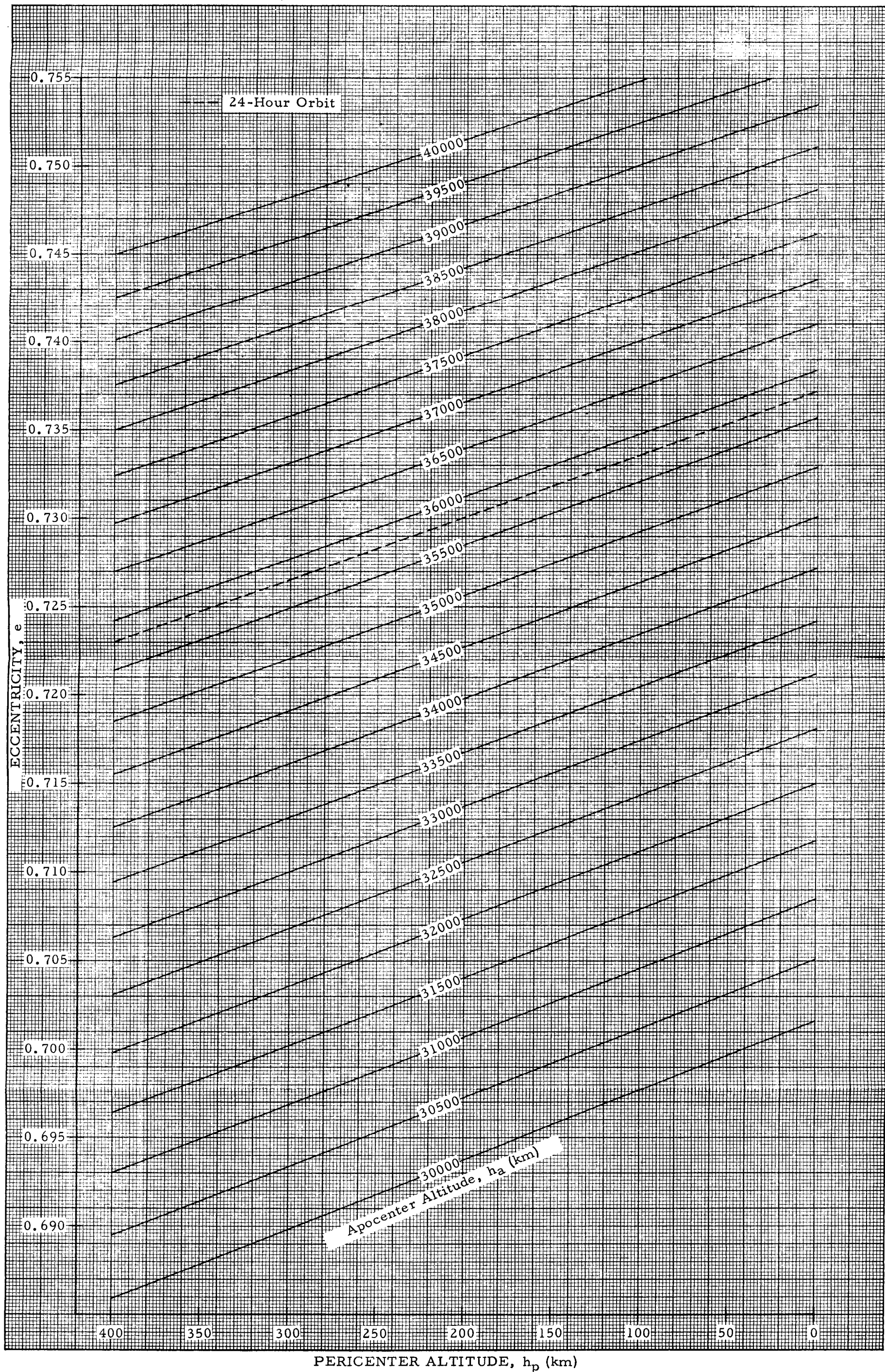


FIGURE 4d. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



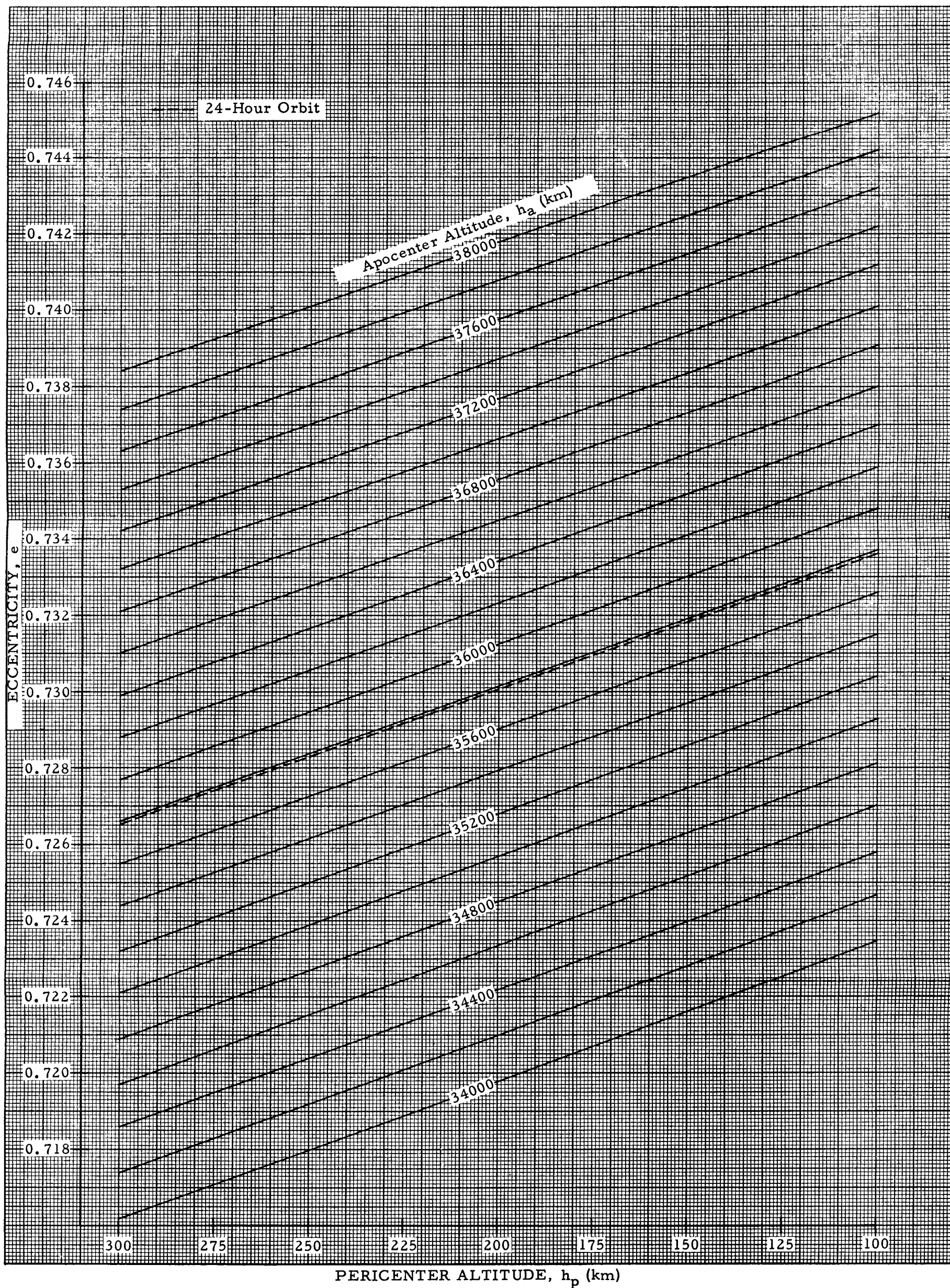


FIGURE 4e. ECCENTRICITY VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

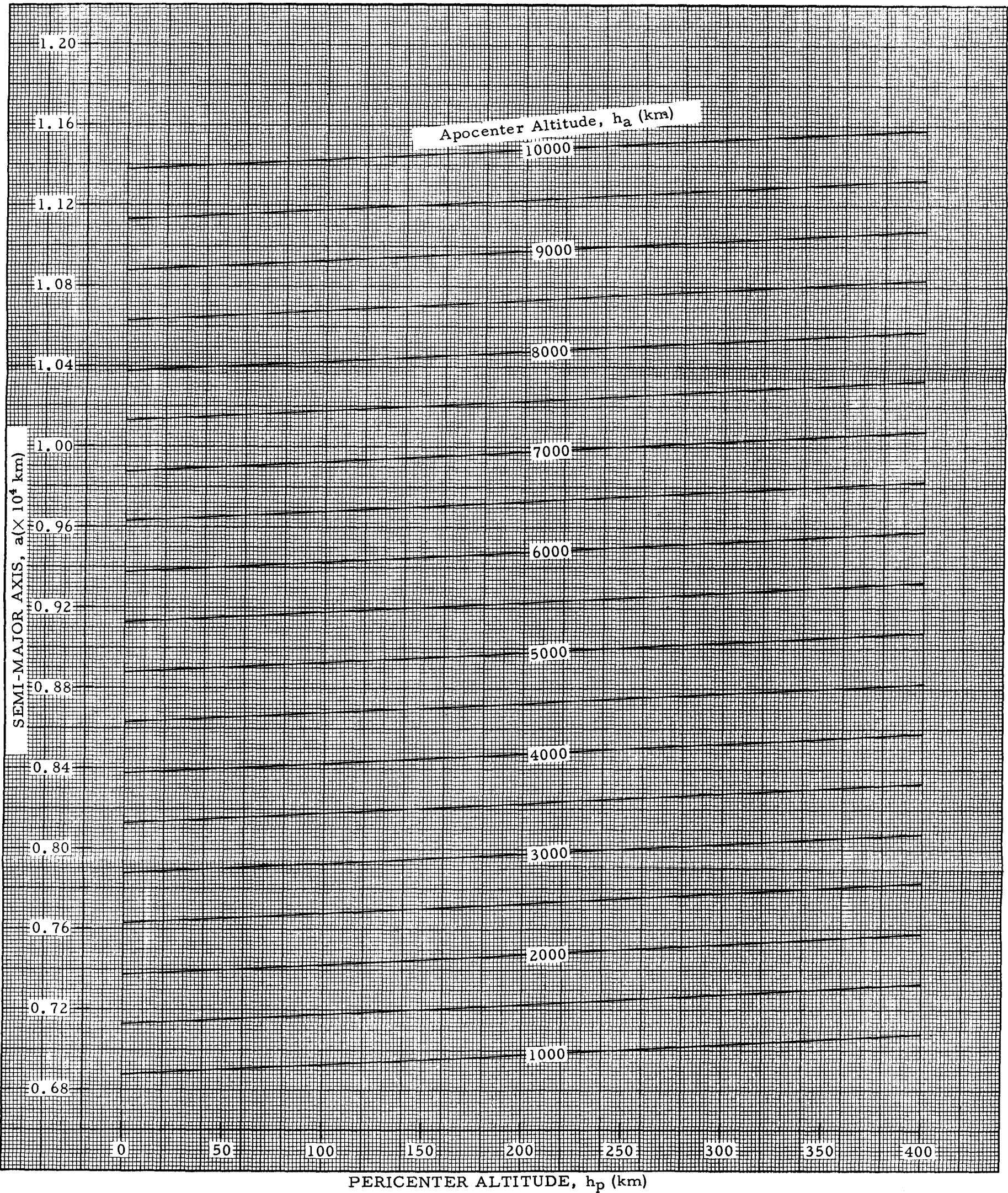


FIGURE 5a. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



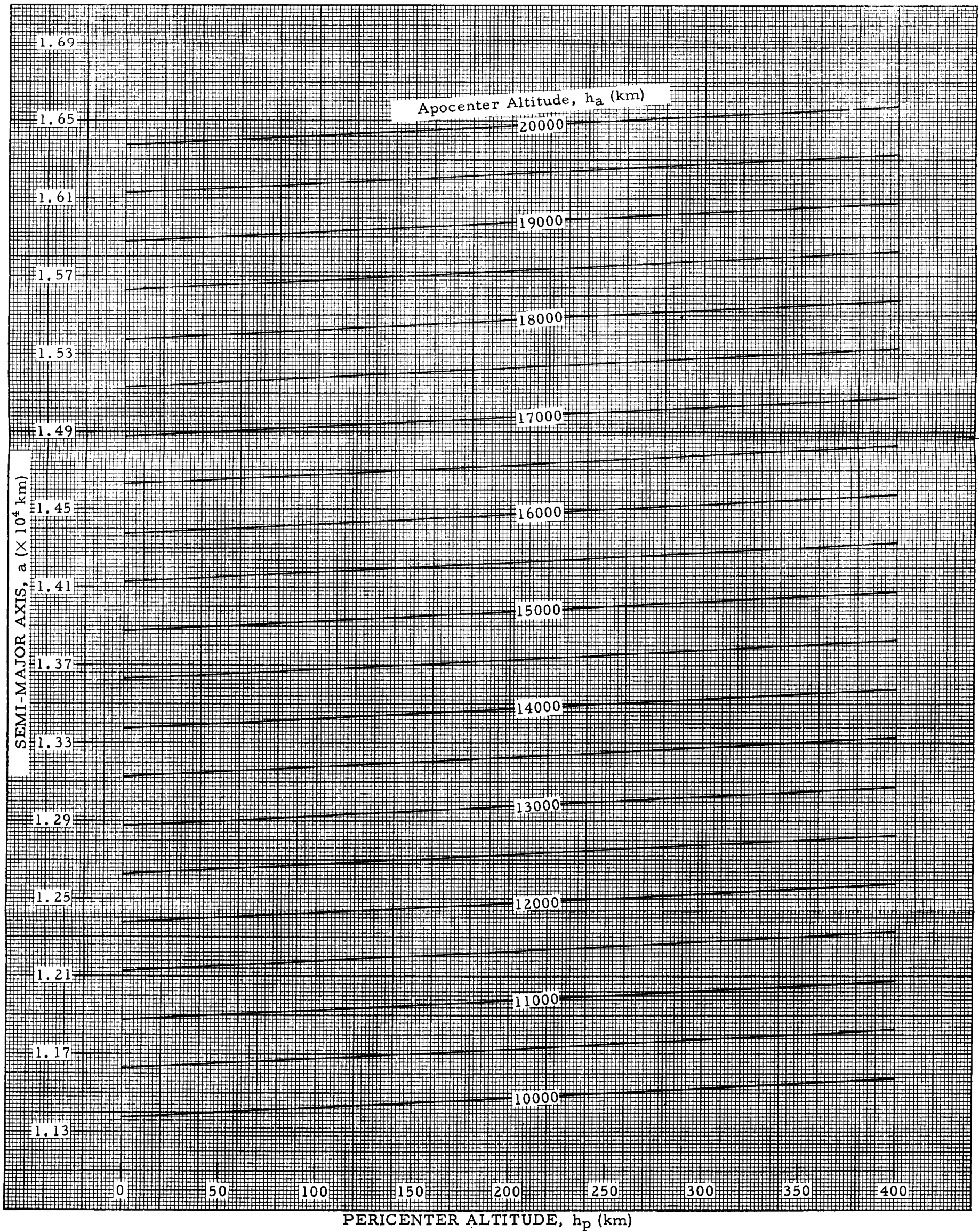


FIGURE 5b. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER

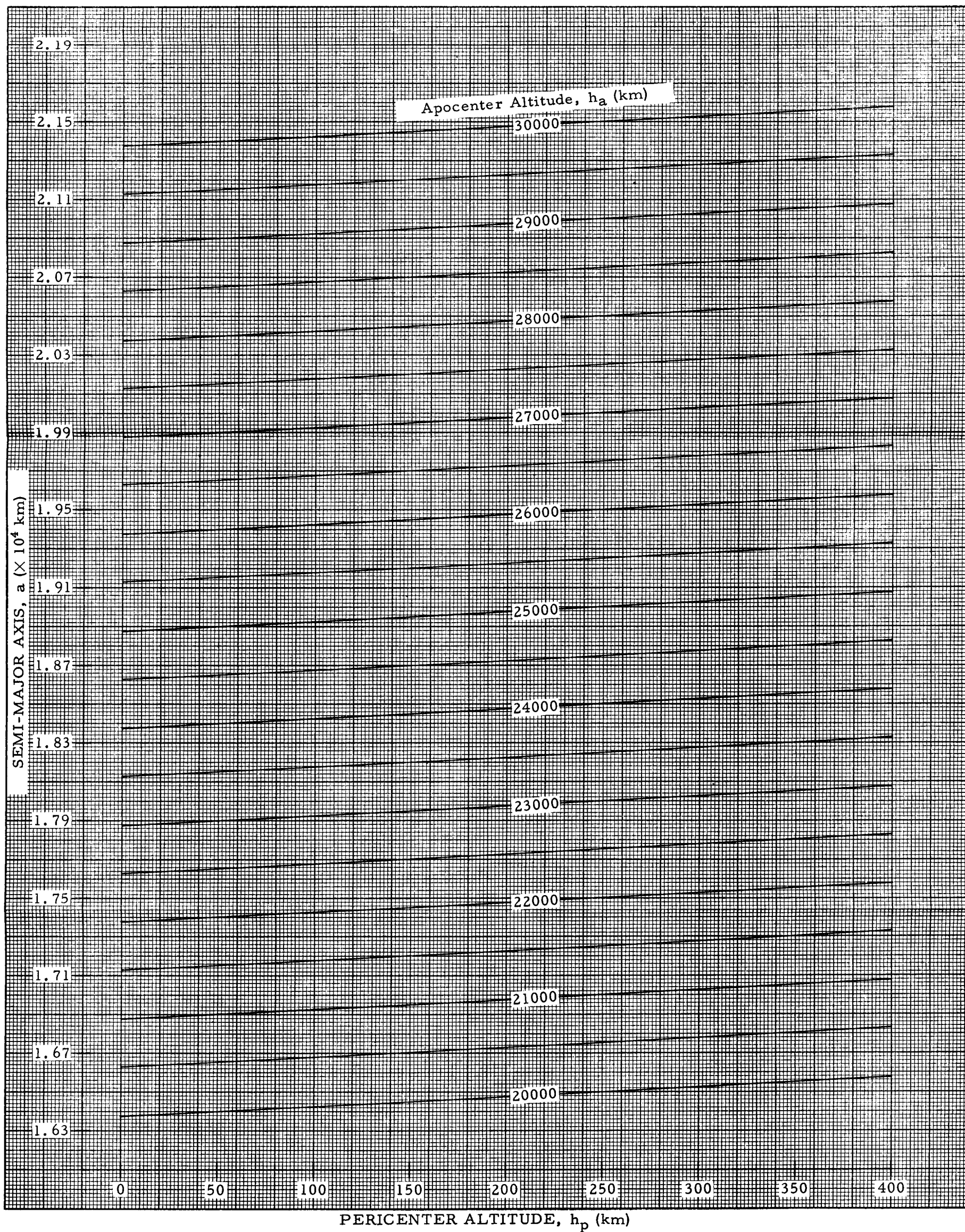


FIGURE 5c. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



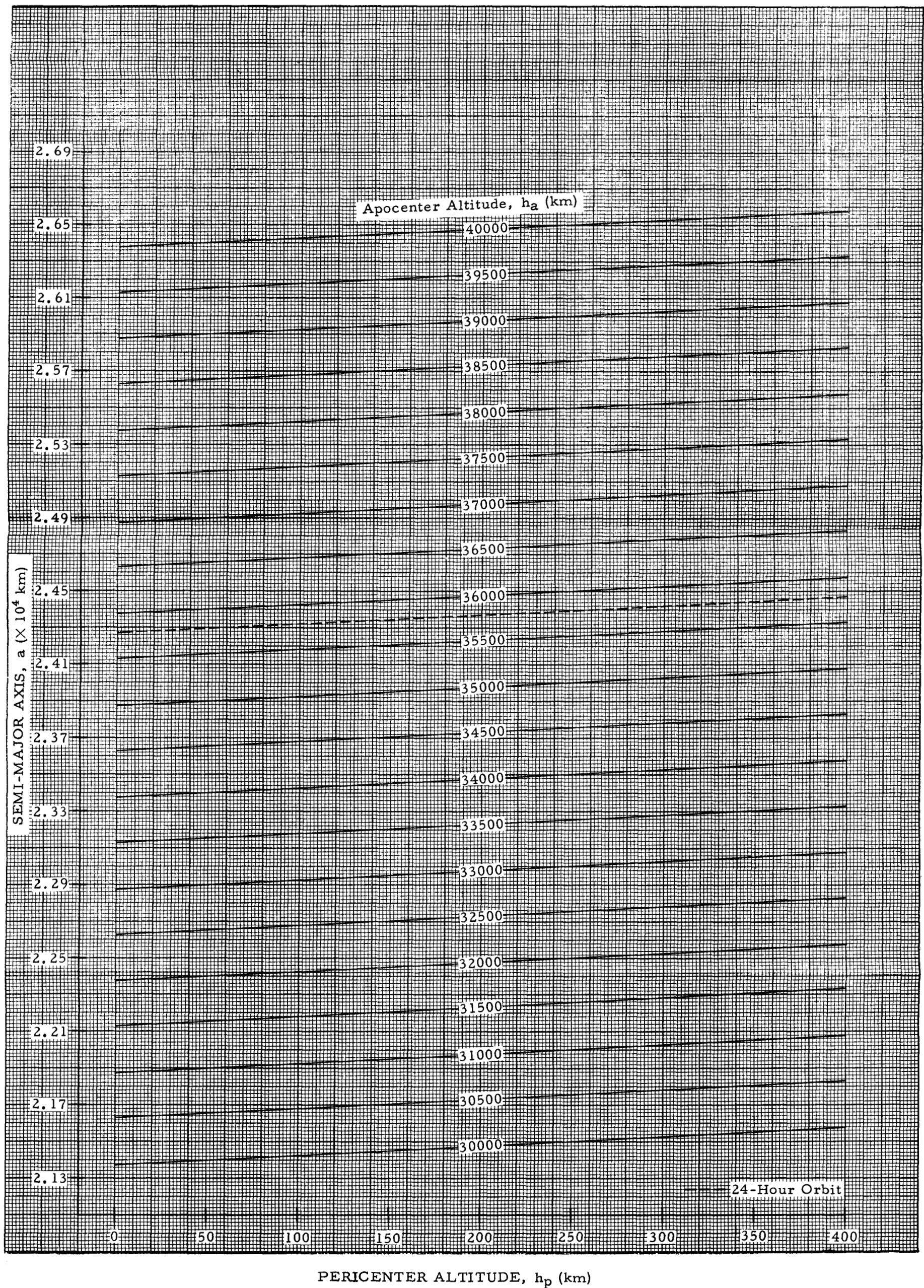


FIGURE 5d. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



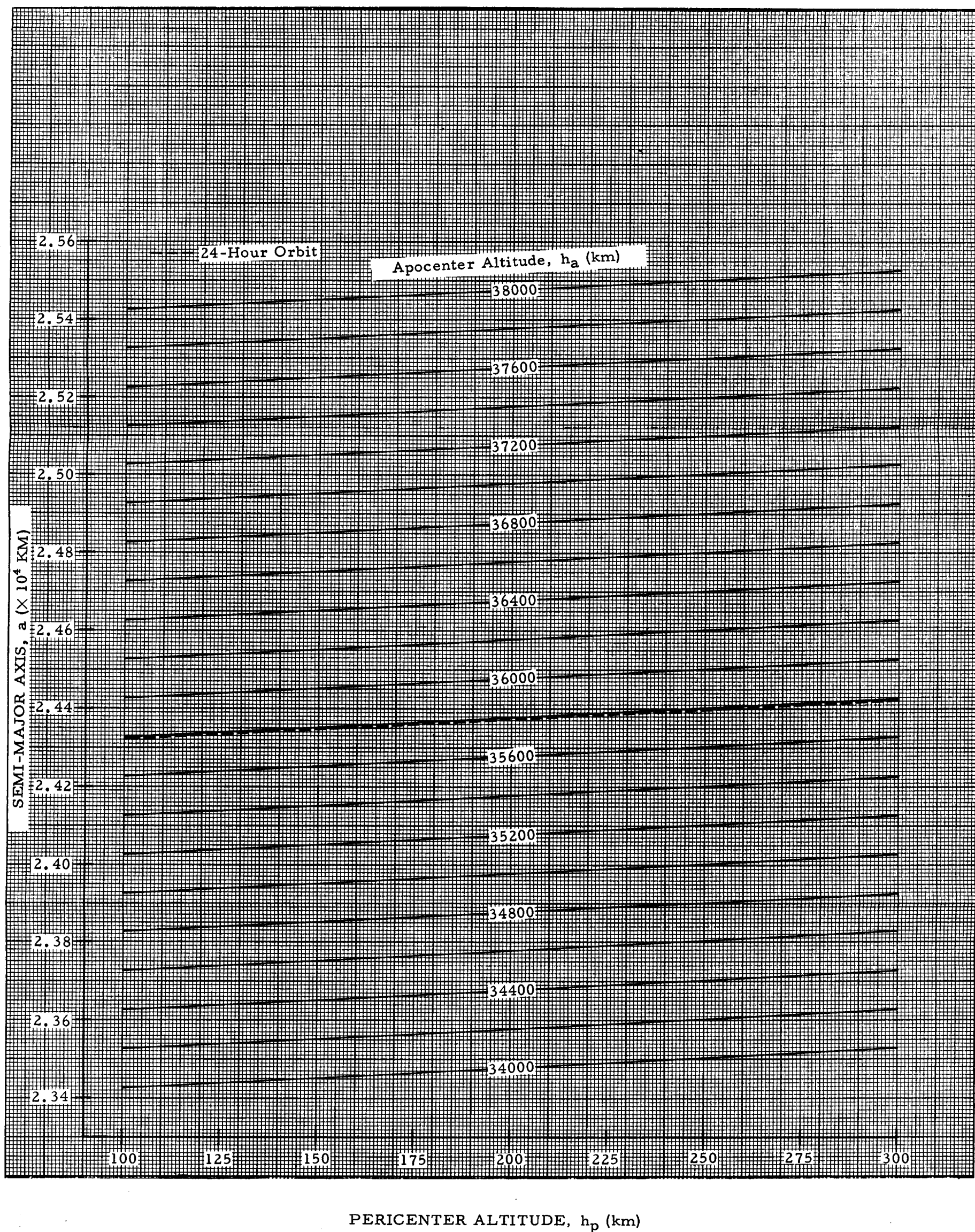


FIGURE 5e. SEMI-MAJOR AXIS VERSUS PERICENTER ALTITUDE WITH APOCENTER ALTITUDE AS A PARAMETER



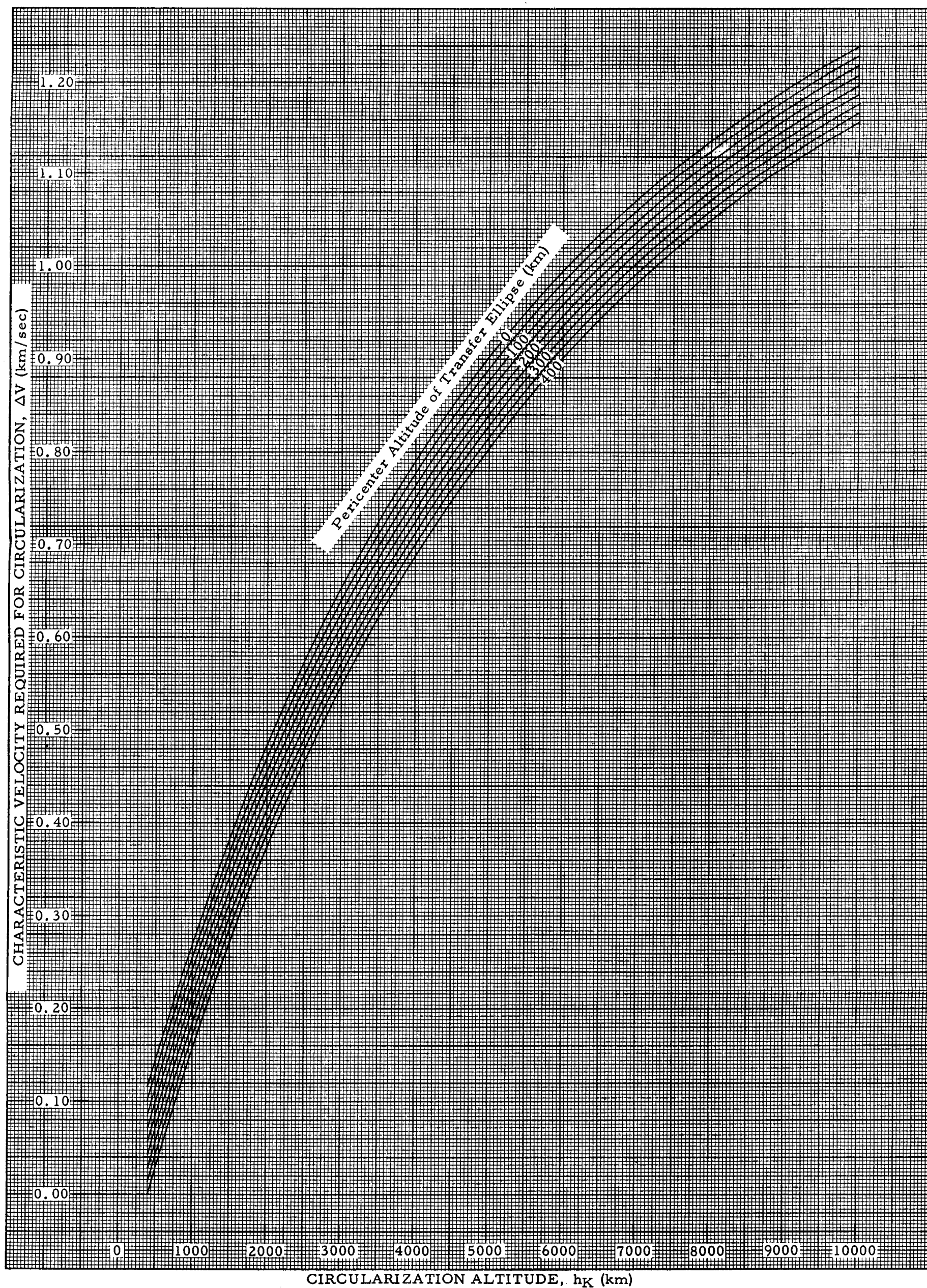


FIGURE 6a. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER

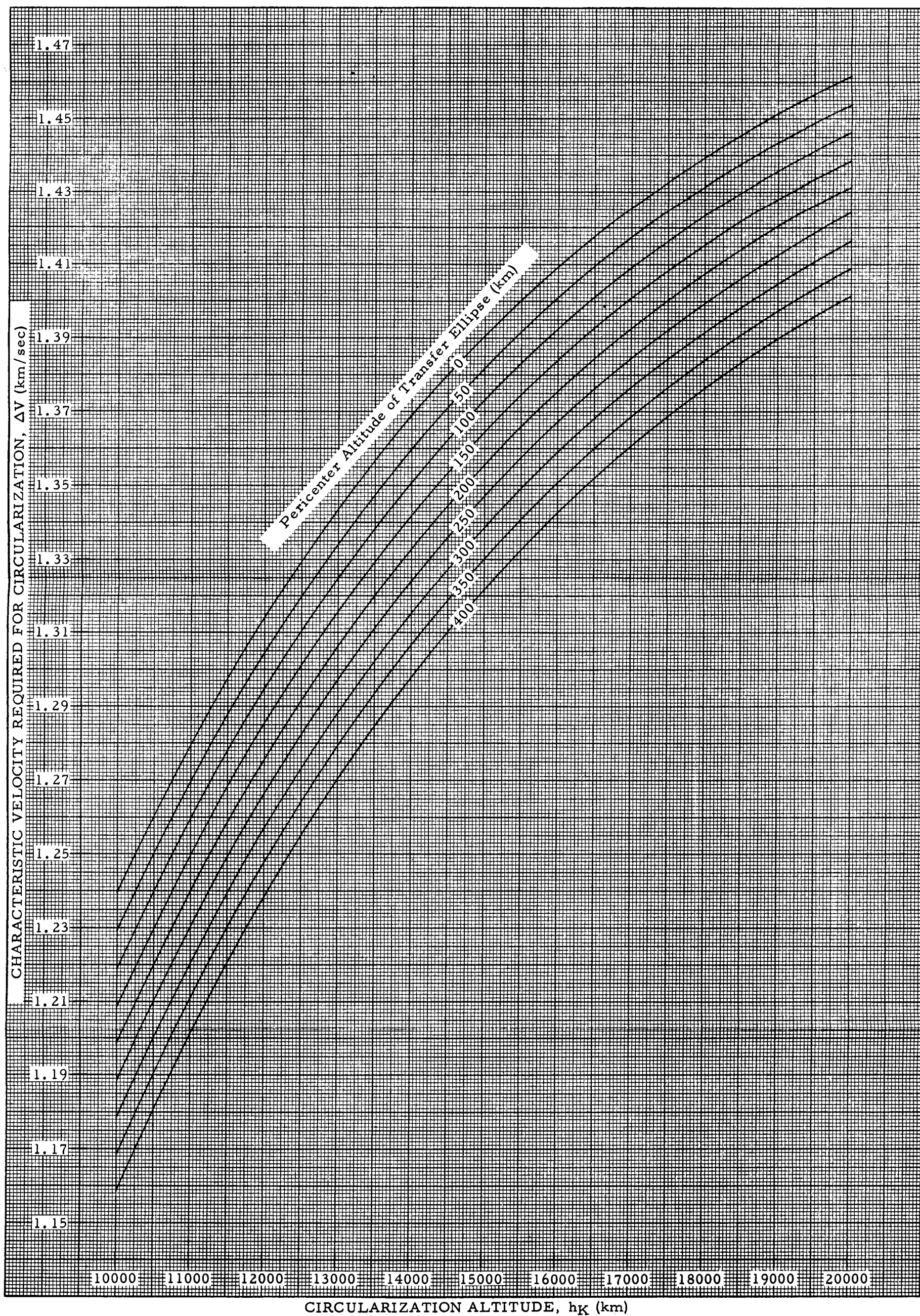


FIGURE 6b. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER



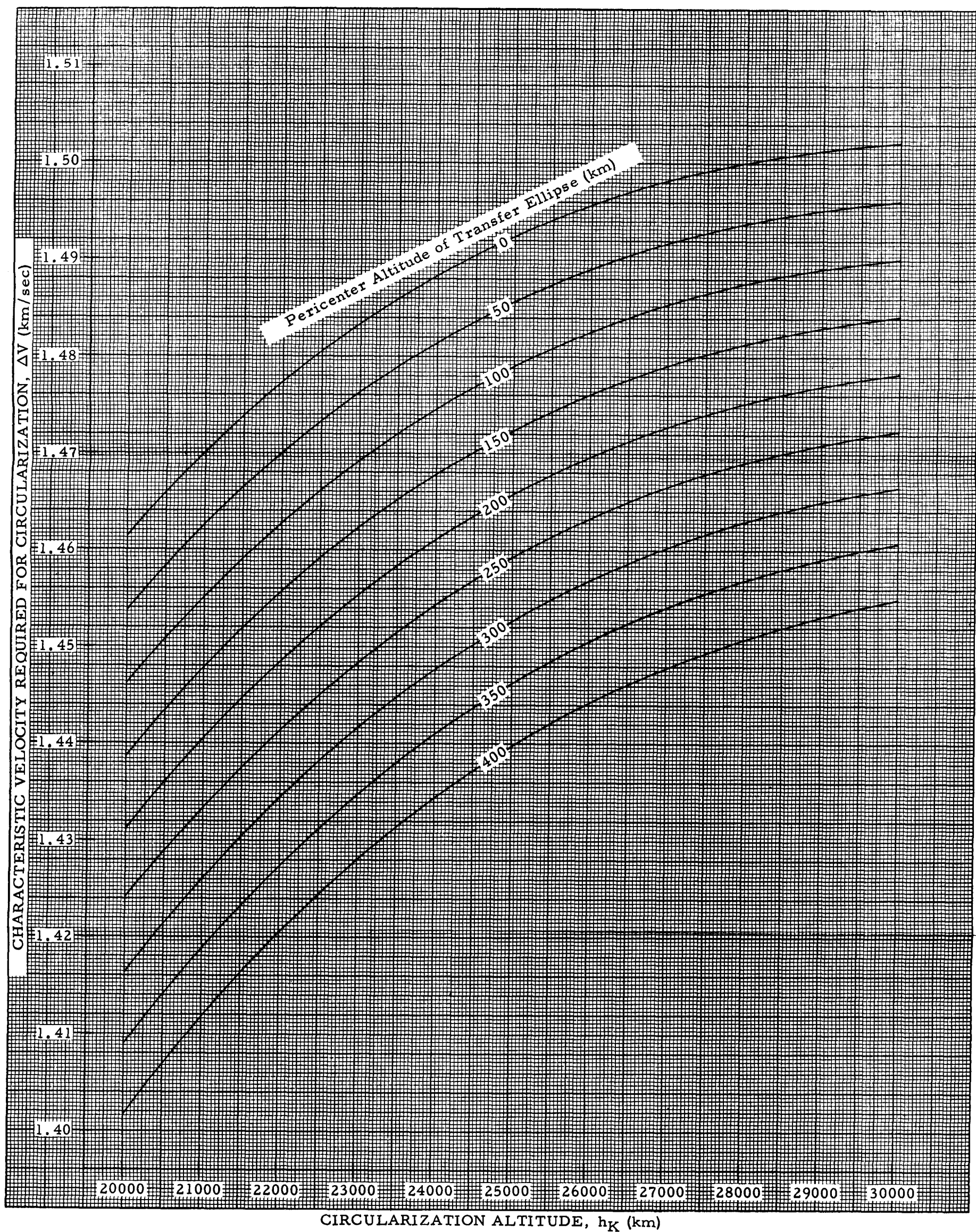


FIGURE 6c. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER



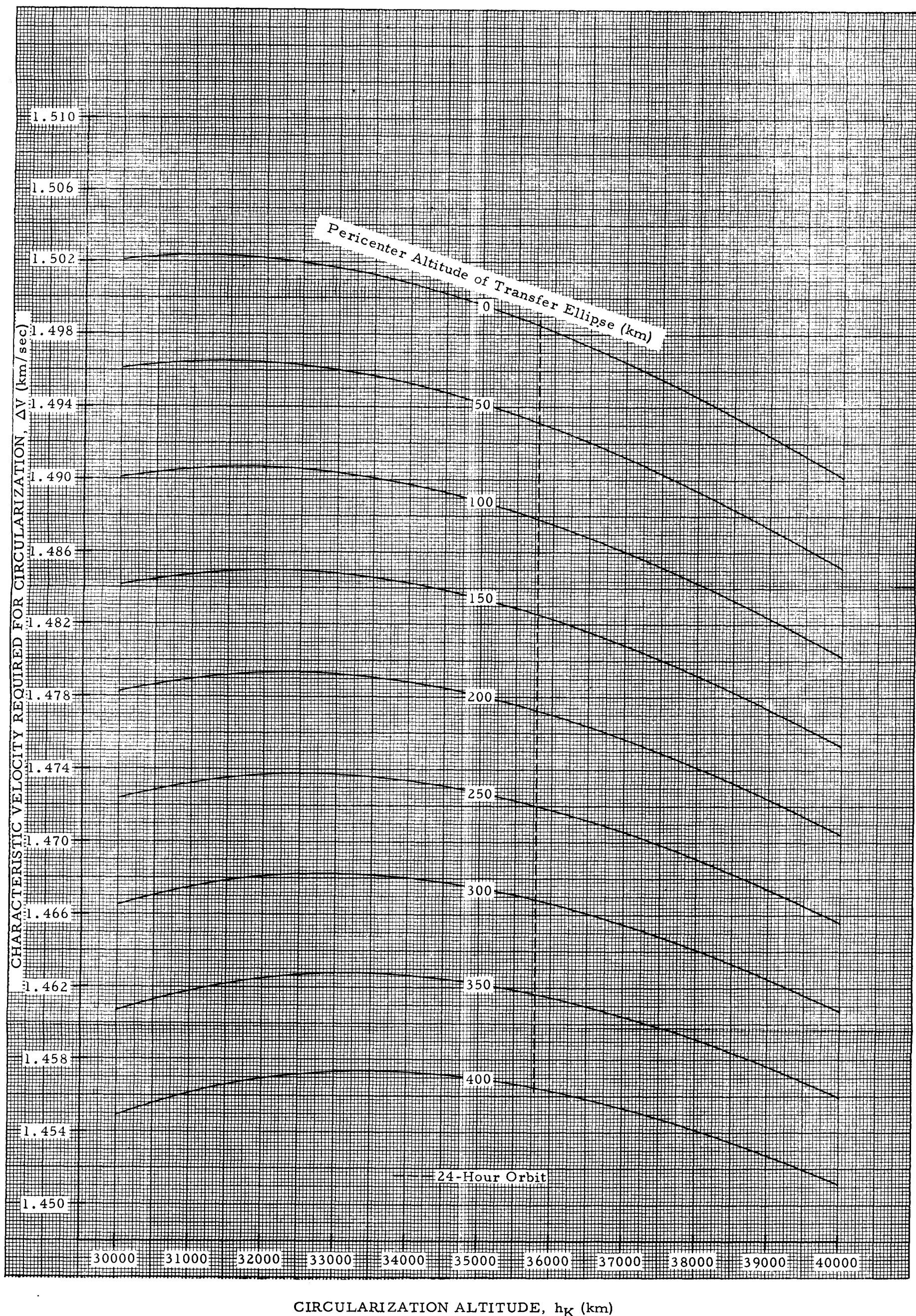


FIGURE 6d. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER



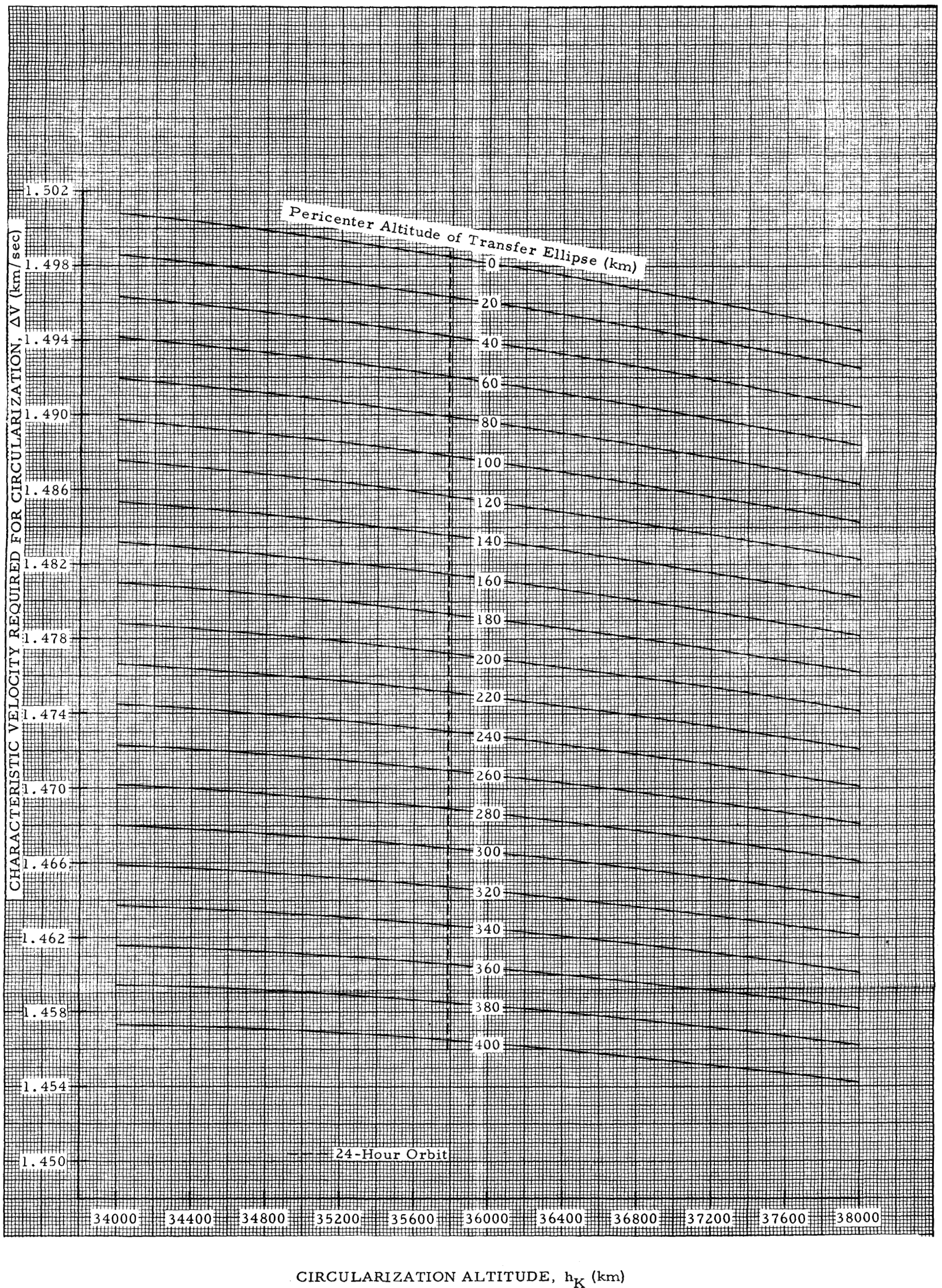


FIGURE 6e. THE CHARACTERISTIC VELOCITY REQUIRED FOR CIRCULARIZATION VERSUS CIRCULARIZATION ALTITUDE WITH PERICENTER ALTITUDE OF THE TRANSFER ELLIPSE AS A PARAMETER

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August 29, 1963

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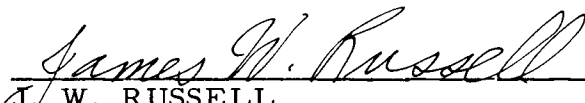
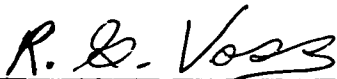
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ORBITAL PARAMETERS FOR ARTIFICIAL EARTH  
SATELLITES UP TO 40,000 KM ALTITUDE

By

Walter H. Stafford  
Sam H. Harlin  
Carmen R. Catalfamo

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